Auromatic Centering on Photographic Star Images

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ABSTRACT

A method for precise centering on photographic star images is proposed. The image is moved only once across one scanning slit for the first coordinate and then across another slit for the orthogonal coordinate.

The photometric values are stored and treated in an on-line computer. The relative opto-mechanical simplicity suggests the application of the method to existing comparators.

INTRODUCTION

When accurate coordinates are measured on a photographic plate, visual centering on the star is still widely applied. In recent decades a number of machines with automatic centering have been developed for the purpose of avoiding personal errors and increasing the speed and reliability of the measuring process.

Detailed information on the machines has kindly been given us by the purchaser or by the firm constructing the machine, since it often is not published in available literature. All methods for centering have in common that they are null-methods requiring the image to be moved by some opto-mechanical device under servo-control. Since this motion under servo-control must be backlash-free within less than 0.5 microns, considerable mechanical problems are encountered. The backlash-free motion may be obtained for the entire plate carriage if it is moving essentially friction-free, for instance on air-bearings. The alternative solution is to introduce additional moving optical parts, *e.g.* a plane-parallel glass plate to accomplish the final setting after the plate carriage has been set approximately on the star.

The method presented below does not require backlash-free motions.

The difficulties described above are multiplied when the x and y coordinates are to be measured simultaneously, since the beam splitting device and the fast rotating scanners introduce a tendency to mechanical instability.

In the following machines the devices for detecting the image being centered apply to either a rotating sector or scanning slits or a spiralling flying spot:

Lentz and Bennett (1954), Vasilevskis and Popow (1968), the U.S. Naval Observatory machine, Grubb Parsons Type PM 20S, David Mann Type 1205, the GALAXY machine.

Some of the machines are semiautomatic in the sense that a human operator is part of the servo loop, since the machine merely produces traces on an oscilloscope screen by which the operator decides whether to move the image to the left or to the right.

The high scanning speeds of the slits, typically 1 mm/millisec, require an intense illumination of the plate which may introduce heating of mechanical and optical parts and consequent mechanical drift. A 450 watt xenon arc lamp is used in the U.S. Naval Observatory machine.

In the proposed method the same setting speed will be achieved by a scanning speed of about 1 mm/sec so that much less intensity is required.

COMPUTER SCANNING

The relative optical and mechanical simplicity of the method is evident from the Figures 1, 2, and 3, and is achieved by introducing an on-line computer in which just one scan in each coordinate is stored.

The star image is scanned by two fixed slits as shown in Figure 1. The scanning is accomplished by moving the plate carriage at a speed which need not be constant, since the photometric measurements may be triggered at equidistant points, *e.g.* every 5 microns, by a digitized plate carriage.

The scans must be analysed numerically by a suitable computer program which may define the center of the star image, as *e.g.* the mid-point between two points where the intensity has a required value. If this intensity is not one of the measured photometric values, an inverse interpolation will give the desired coordinate of the point.

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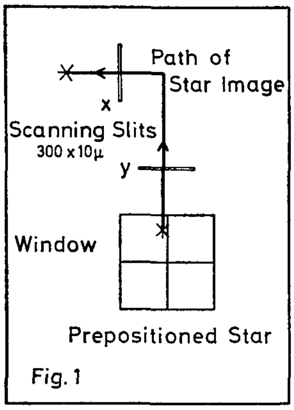

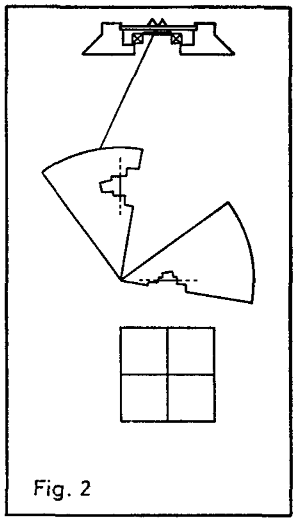

Fig. 1
The star image is prepositioned approximately on the vertical line of the cross in the window. The image is then scanned by the two completely fixed slits which are each coupled to a photomultiplier and subsequently to the on-line computer. The photometric values corresponding to equidistant points on the plate are stored in the computer.

Fig. 2
An arrangement for varying the slit lengths without moving the slits: 300, 200, 100, and 60 microns are possible here. The plate with the step diaphragm is mounted on the inner ring of a ball-bearing centered where the two slits would cross each other. The two slits are situated on the lower surface of the upper plate, the step diaphragm on the upper surface of the lower plate and therefore practically both in focus. The small 60° prisms for splitting the beams are stuck to the upper surface as shown.

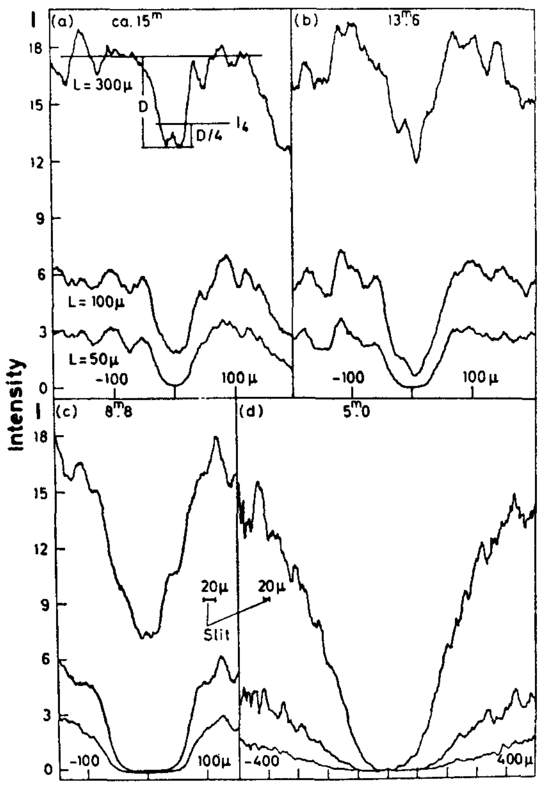

Fig. 3
Microphotometric traces of 4 star images on a plate (4^m exposure on Perutz Astro, transmission of the back ground 0.19) obtained by the Hamburg Schmidt Telescope (80/120/240 cm) the sharp images being typical for a telescope of short focal length. The slit width was 20 microns, three different slit lengths L were used for each star.

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The width may be evaluated as the distance between the two points where the intensity has a fixed value and will be a measure for the magnitude.

How the definition of the midpoint and width should best be chosen could be decided from traces of stars of different magnitudes scanned with different lengths of the slit. In Figure 3a the intensity I_4 at one fourth of the depth above the bottom of the curve (one fourth value point) has been indicated. This definition will be usable for all magnitudes, whereas a half value definition would give ambiguities for very bright stars, the slope of the trace being very small at this point (*cf.* Fig. 3d), partly because of the diffraction cross. Theoretical formulae based on the measured graininess of photographic plates could be set up, giving the expected mean error of a position measured in this way, but at the present time it is sufficient to remember that well-blackened images have indeed been measured automatically by a scanning slit on the U.S. Naval Observatory machine. A digital computer analysis as proposed here can perform at least as well as the image analysis by any analogue method. The method proposed has the advantage that different slit lengths can be applied for different magnitudes, which is particularly important with a great range of magnitudes to be measured on each plate, *cf.* Figure 3. Otherwise, the long slit necessary for the large images would add too much noise from the plate background when a small image is measured. As the slit length at the U.S. Naval Observatory machine cannot be changed, it can only center automatically on stars with diameters between 80 μm and 350 μm.

Theoretically, a slit scanning method will show a greater mean error due to graininess than a rotating sector (or a spiralling flying spot), and it will be more often disturbed by adjacent stars. We guess that the mean error of a position owing to graininess will be $\sqrt{2}$ times greater provided the slit has its optimal length which is equal to the diameter of the image. This difference in performance is of importance only for the smallest images.

If the computer is provided with two digital-to-analog converters and a real time clock, the scans may be traced on an oscilloscope screen. The traces familiar from any of the known slit scanning methods may be simulated and used by the operator for comparison.

The required accuracy of the positioning of the star before the scan is about ± 0.2 mm in y, since the y-motion may be stopped by the computer, after the y-scan has been obtained, at a point where the image will then cross the midpoint of the x-slit. If it then turns out that the prepositioning in x was not accurate enough, the y-scan must be repeated.

An optical lay-out suited for implementing this method for the David Mann Type 422 Comparator is given in Figure 4. With this machine it should be kept in mind that a continuous motion of the screws at 2.5 mm/sec causes a differential heating of the screws of 1°C when equilibrium has been attained, which will shift the whole plate about 2 μm when the scanning is always started from the same direction. If, however, both forward and backward scanning is carried out, the mean value will be more nearly free from the effect of differential heating of the screws.

It is quite obvious that the cost of an automatic measuring machine, now being at least U.S. $220 000, could be cut down drastically, since the David Mann machine and the on-line computer cost about U.S. $35 000 each. The extra facilities offered by some of the existing machines in order to increase convenience and speed will not justify the higher expense for all potential users.

REFERENCES

Lentz, J. and Bennett, R., 1954. *Electronics*, **27**, 158.

Vasilevskis, S. and Popov, W. A., 1968. *Lick Obs. Bull.* No. 598.

DISCUSSION

W. A. SHERWOOD: How many stars per hour do you expect to measure?

E. HØG: The centering process could be finished in 10 sec or less; how long it will take to go from star to star depends on the star density. With the Mann machine it is a problem making it automatic because of heating: if you move the carriages continuously at the maximum speed of 2.5 mm/sec, the screws heat up 1° at temperature equilibrium, and that will shift the image by 2 μm at the centre of the plate. So you could not move at maximum speed, unless you measure in both directions, when the mean value will be partially freed from this shift of zero-point, because only the screws are heating, and not the ends of the carriage on the screw.

G. S. WALKER: What form of analog-to-digital conversion is used? Is the signal-to-noise ratio for saturated images improved by weighting, in the examination of the digital data, to exclude the saturated region?

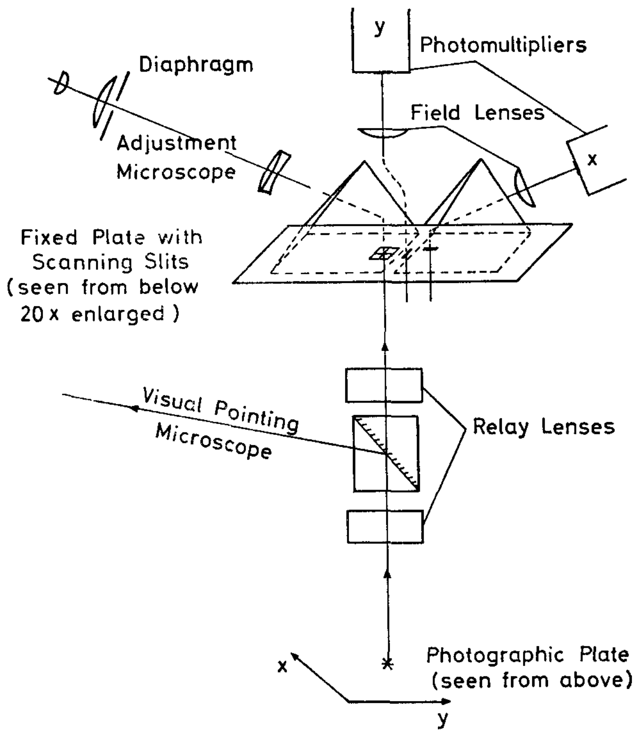

Fig. 4

An optical system suited for the David Mann Comparator. The fixed plate with slits and beam splitting 60° prisms is seen from below and enlarged about 20 times. The other components are shown in simple projection.

E. HøG: Both points are open; what I have presented is only a proposal at the moment. It seems that centering can be done by a slit, as is done in the U.S. Naval Observatory machine; it is quite evident, I think, that what can be done by analog means can be done also in the computer.

G. B. PARRENT: Are you suggesting that you can define the slit-width as an arbitrary fraction of the height, taking the 6αB points as defining the true width of the image, and the centre half-way between? Is the purpose of this double scanning simply to get a profile on which you would measure some preset distance from the maximum? You would need to correct in the computer for the smoothing produced by your 20 μm slits.

E. HøG: A decision about how to define the centre of the image need not be taken now. The computer leaves all possibilities open to the user when he has the equipment delivered.

J. TINBERGEN: In going to the expense of a computer, yet using a traditional slit system, you would seem to lose the main advantage of the computer. If you spot-scanned a two-dimensional region and analysed the resulting raster of data-points, you could discriminate against all sorts of unwanted data, such as non-circular images and dust. If your computer is too fully loaded for this, simple slit-scanning could still be simulated at little cost in computing time.

E. HøG: The main advantage of the inexpensive computer in the proposed system is that fixed slits can be used, and that backlash-free carriage motions are not required. A raster scan can be performed by this instrument since the slit-length can be changed easily. In order to avoid difficulties with storage space and computing speed, it is convenient that the slit-length could be changed according to the size of the star image to be measured. Instead of the scanning slits, an array of say 30 solid-state detectors, each measuring an area of 10×10 μm, may be advantageous. This would require a more elaborate computer program, but higher measuring speed, better resolution, and higher accuracy could be obtained.