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A NEW DEVICE FOR SOLAR OBSERVATIONS

Summary : After a review of the main causes of the relative inaccuracy of solar observations as compared with star observations, a new device — a "solar prism attachment" to be fitted over the objective of a normal theodolite — for increasing the accuracy and facilitating the observations is described. The results of several practical observations are discussed.

§ 1. **Introduction.** — It is a well-known fact that solar observations (for determining azimuth, latitude or longitude) are less accurate than star observations. The main causes are :

a. The relative inaccuracy of pointing on the limb of the sun.
b. The influence of the sun's heat radiation on the theodolite.

Some remarks on these difficulties will be made in this paragraph.

a. As it is impossible to point on the centre of the sun, owing to the largeness of the sun's disk, it is customary to place the image of the sun in the field of view of the telescope in such a position that it is tangent to :

α the vertical wire in the case of a determination of azimuth by hour-angle.
β the horizontal wire in the case of a determination of longitude by altitude or in the case of a determination of latitude by circummeridian altitude and hour-angle.
γ both vertical and horizontal wires in the case of a determination of azimuth by altitude.

In the cases α and β the telescope is clamped when the image of the sun occupies a position just prior to tangency and the timekeeper is read at the instant when the disk is tangent to the wire. In the case γ the vertical wire is kept continuously on the right or left limb by means of the horizontal tangent screw and this motion is stopped at the moment when the disk is tangent to the horizontal wire equally.

In all cases systematic personnal errors may be introduced by a too „thick" or too „thin" tangency of limb(s) and wire(s). The question arises whether it is possible to eliminate these errors by observing opposite limbs successively and pairing the observations.

This is not so inasmuch as it is preferable to observe always the very limb which appears to *leave* the wire, the latter being badly or not visible (depending on the clearness of the sky) outside the sun's disk. But even when the wire is passably visible in the dark part of the field of view — due to a veiled sky — the tangency errors may not be expected to be equal for limbs approaching a not or badly visible wire or leaving a clearly visible wire.

In the case γ, where the vertical wire has to be kept continuously tangent to the disk the difficulty of this wire being then badly or not visible is evident. In this case there is a much more serious source of errors however. The exact pointing of the telescope is attained at the instant when both cross-wires are *simultaneously* tangent to the sun's disk. For ascertaining this the observer has to turn his attention to both tangency-points, which are a large distance (approximately 22') apart. Theoretically he should observe these tangency-points simultaneously, but in practice he can only try to observe them *alternately* as quickly as possible. As a consequence of this the observation is weary, unquiet and inaccurate.

b. As a direct observation of the sun through the telescope is not possible, due to the intense light, a coloured eyepiece-sunglass is used or the image of the sun and the cross-wires are brought to a focus on a white piece of paper, which is held in the rear of the eyepiece.

The objective lens focusses the untempered rays of sunlight in the plane of the wires or — in modern instruments — crosslines engraved on a glass diaphragm. In the same time however the objective lens focusses the rays of *sunheat*; it operates as a burning glass, causing in the latter type of instruments an extreme heating of the glass diaphragm and to a less extent of the diaphragm ring, which involves expansion and tension. As according to the methods of observation described before, the position of the sun's image in the field of view is eccentrical, the centre of expansion does not coincide with the centre of the diaphragm. This may cause an irregular expansion of the glassplate and diaphragm ring, resulting in a displacement of the point of intersection of the cross-lines. The importance of this phenomena may be evident from the fact that a displacement of only 0,01 millimeter (0,004 inch) produces a lateral or vertical collimation error of 10″ if the length of the telescope is 20 centimetres (8 inches). The position of the sun's image in the field of view not being constant, these collimation errors are not constant either and therefore can not be eliminated completely by repeating the observations with a reversed telescope and taking the mean of the results.

§ 2. **Description of the new device ("solar prism attachment").** — In order to overcome the difficulties described in the preceding paragraph a special device for solar observations has been designed. It consists of a pair of small prisms mounted perpendicular to each other in a short tube *a*, which has been attached to a collar *b* by means of a hinge *c* (fig. 1). The tube has been closed at the front end by a green filter glass and at the other end by a gray filter glass. The device may be attached in front of the objective of a normal theodolite (fig 2. and 3), the collar *b* fitting over the frame of the objective lens.

In the position shown in fig. 2 one of the prisms is in front of the upper half of the objective lens, whereas the other prism is in front of the right hand half of it (fig. 4). From this it is evident that in front of :

the upper left-hand	quadrant	of	the	objective	is the first prism
the lower right-hand	,,	,,	,,	,,	,, ,, second ,,
the upper right-hand	,,	,,	,,	,,	are both prisms
the lower left-hand	,,	,,	,,	,,	is no prism.

The effect of this is to produce *four images of the sun*, arranged in a square as is shown in fig. 5.

The refracting angle of the prisms has been made 23′10″ in order to have the four sun's disks overlap eachother in pairs, the overlapping parts forming a brigth cross (fig. 5). In the centre of this cross is a small dark square of 10″ x 10″ (in winter) to 75″ x 75″ (in summer) depending on the apparent size of the sun's disk.

The filters produce monochromatic green images of the sun comfortable to the observer's eye and reduce the sunlight and sunheat wich enter the telescope to a minimum, thus preventing the diaphragm glass and-ring from extreme heating.

The object to point at is the brigth green cross formed by the overlapping parts of the four sun's images. Pointing on this symmetrical object has several advantages over the use of a single image of the sun :

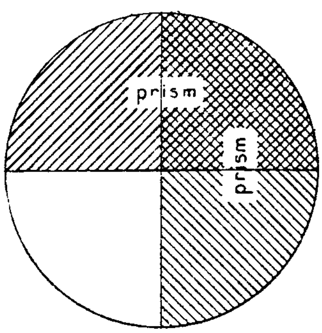

Fig. 4. — Position of the prisms in front of the objective.

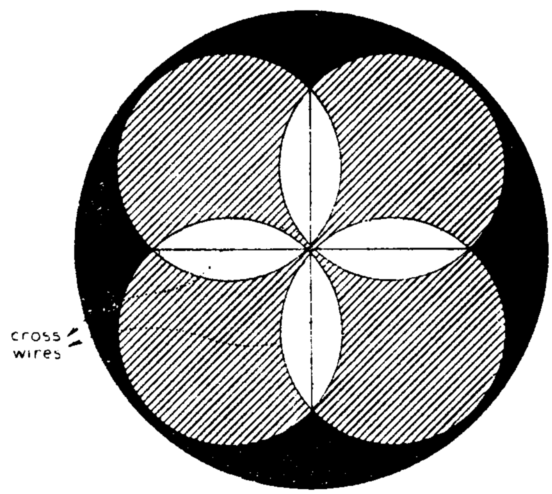

Fig. 5 — Four images of the sun simultaneously in the field of view of the telescope.

a. high accuracy, exact pointing being established by observing the wires to bisect the "wings" of the bright cross. (fig. 5.)
b. no personal systematic tangency errors.
c. wires always clearly visible upon the sun's images.
d. no confusion about the choice of wire-quadrants.
e. correction of the observed altitude independent of the sun's semidiameter, it being equal to the half of the refracting angle of the prisms.
f. correction of the observed azimuth independent of the sun's semidiameter, it being equal to the half of the refracting angle of the prisms, devided by the cosine of the observed altitude.

§ 3. **Adjustment and use of the solar prism attachment.** — After the prism attachment has been placed over the objective, the telescope is sighted on the sun and the attachment is rotated by hand until the wings of the bright cross, formed by the overlapping parts of the sun's images, are parallel to the wires. Now the clamp screw *d* (fig. 1) is tightened, thus keeping the attachment in its right position throughout the whole program of observations. It is emphasized that a slight error of this simple adjustment has quite the same effect as lateral and vertical collimation errors and is therefore eliminated by transitting the telescope between successive observations.

When pointing on the sun the tube containing the prisms and filters is in its normal position in front of the objective (fig. 2). Before pointing on an azimuth mark the prisms and filters are eliminated by hinging the tube laterally (fig. 3). As the prisms have been mounted in the tube in a position of minimal deviation a slight error in the position of the tube after having it hinged back in front of the objective, causes no appreciable effect in the results of the observations.

§ 4. **Accuracy**. — In order to examine the accuracy obtainable by applying the new device the K.L.M.-surveyor Mr. P. de With, in charge of supplying ground control for a photogrammetric survey of Dutch Guyana (latitude = + 5°49', longitude = 55°09' W) made a number of observations on my request, the results of which will be discussed in this paragraph.

Azimuth by altitude of the sun.

The schedule of observations was as follows :

1. Pointing on the ground mark (steeple) and reading the horizontal circle.
2. Pointing on the sun and reading horizontal and vertical circles.
3. Same as 2.
4. Same as 1.

This series of observations was repeated four times; the telescope was transitted between the second and third series.

Between each two successive series the horizontal circle was rotated 45° with a view to eliminate systematic circle graduation errors.

TABLE 1.

Date of observation (1947).	Computed azimuth.	Mean error of a single observation	Mean error of the computed azimuth.
21-1 p.m.	234° 54′ 2″,9	5″,9	2″,0
22-1 p.m.	7″,3	4″,3	1″,5
23-1 a.m.	10″,1	5″,1	1″,8
24-1 a.m.	4″,5	4″,0	1″,4
24-1 p.m.	5″,8	6″,5	2″,3
final mean	234° 54′ 6″,1	5″,2	1″,8

No striding level being available the theodolite (*a "Wild" type T*2) was leveled carefully before *each* series, the effect of leveling errors thus having the character of random errors. Each *half* series (to be called a *"single observation"*) was computed separately. From the eight values of the azimuth thus obtained the mean value and the mean error as well as the mean error of a single observation were derived.

The observations according to the above-mentioned program were repeated five times; table 1 shows the results.

Obviously the mean *internal* error of a computed azimuth is 1″, 8 on an average. The mean *external* error may be derived by comparing the azimuths with the final mean, shown in table 1, and turns out to be 2″,8. The difference between the internal and external accuracy may be attributed to systematic errors of the astronomical refraction and errors of setting up the thedolite over the stake.

Executing the program of four series (eight single observations) required 32 minutes on an average, i. e. 4 minutes per single observation.

Azimuth by hour angle of the sun.

The schedule of observations was much the same as described before with this difference that a time-keeper was read instead of the vertical circle. Table 2 shows the results of four sets of observations.

TABLE 2.

Date of observation (1947).	Computed azimuth	Mean error of a single observation.	Mean error of the computed azimuth.
25-2 p.m.	234° 54′ 4″,9	5″,5	1″,9
26-2 p.m.	10″,2	4″,7	1″,7
28-2 a.m.	9″,3	5″,3	1″,9
28-2 p.m.	4″,6	4″,0	1″,4
final mean	234° 54′ 7″,2	4″,9	1″,7

The mean *external* error of a computed azimuth, derived by a comparison of the azimuth with the final mean, is 2″,9.

The difference between this value and the mean *internal* error (1″,7) may be attributed to errors of the time-keeper and errors of setting up the theodolite over the stake. Some errors may be introduced also due to the circumstance that the corrections to the time signals were not yet known when the observations were computed. The time required for the execution of a complete program was 28 minutes on an average, i. e. 3,5 minutes per single observation.

Azimuth by hour-angle of stars.

In order to have another check on the results from the solar observations the azimuth was determined twice by star observations using the same instruments (without using the attachment of course). The program of observations was similar to the schedule used for the solar observations. Table 3 shows the results.

TABLE 3.

Date of observation (1947).	Star.	Computed azimuth.	Mean error of a single observation.	Mean error of the computed azimuth.
12-5	α Ophiuchi	234° 54′ 5″,6	4″,4	1″,5
12-5	α Leonis	5″,0	3″,8	1″,4
final mean		234° 54′ 5″,3	4″,1	1″,5

A comparison of the values of the tables 1-3 leads to the conclusions :

a. that the results of the sun-and star-observations agree within the margin of accuracy.

b. that solar observations by means of the prism attachment are almost as accurate as star observations.

Latitude by circummeridian altitudes of the sun.
Longitude by altitude of the sun.

Although the main application of solar observations uses to be for determination of azimuth, some determinations of longitude and latitude were made in order to get a still better estimation of the accuracy of pointing a telescope fitted with a solar prism attachment on the sun. That determinations of latitude or longitude are apt indeed to give such a better estimation follows from the fact that the results are not (as in the case of azimuth-determinations) influenced by :

a. errors of leveling the theodolite.
b. errors of setting up the theodolite over the stake.
c. errors of pointing on a ground mark.
d. errors of reading and graduation of the horizontal circle.

From the computed mean errors of a single determination of latitude (m_φ) resp. longitude (m_λ), the mean error of a single observation of altitude (m_h) has been derived (assuming the errors of the time-keeper, the rate and the reading of it to be negligible) by the formulae :

$$m_h = m_\varphi \qquad \text{resp. } m_h = m_\lambda \cos\varphi \sin a.$$

in which :

φ = latitude of the station.
a = azimuth of the sun.

The time required for a single observation was 2,4 minutes (determination of latitude) resp. 1,3 minutes (determination of longitude). The mean error of a single observed altitude (errors of the time-keeper, the rate and the reading of it, errors of the graduation and reading of the vertical circle and errors in the centering of the vernier control bubble included) turns out to be round 3″ (See Table 4).

Table 4 shows the results :

TABLE 4.

Date of observation (1947).	Determination of :	Number of observed altitudes.	Mean error of a single observed altitude.
27-1	latitude	13	3″,4
28-1	,,	16	3″,2
		mean :	3″,3
1-3	longitude	16	2″,8
4-3	,,	16	3″,0
4-3	,,	16	2″,9
		mean	2″,9