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Semiautomatic sun shots with the WIDIF DIflux

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Abstract. The determination of magnetic declination angle entails finding two directions: geographic north and magnetic north. This paper deals with the former. The known way to do it by using the sun's calculable orientation in the sky is improved by using a device based on a WIDIF DIflux theodolite and split photocells positioned on its telescope ocular. Given the WIDIF accurate timing and location provided by the onboard GPS receiver, an astronomical computation can be effected to accurately and quickly determine the sun's azimuth and an auxiliary mark's azimuth. The precise sun's crossing of the split photocell, amplified by the telescope's magnification, allows azimuth accuracies of a few seconds of arc.

1 True north

The determination of true north via the mark's azimuth required for magnetic declination is an old problem which has received a number of solutions (Šugar et al., 2013): by sun shot, north-seeking gyroscope (Rasson and Gonsette, 2016) and GPS techniques (Lalanne, 2013).

The sun shot technique, although potentially quick and accurate, is not very popular. The reason probably stems from fear of suffering eye damage when trying to point a telescope towards the sun, the supposed difficulty of astronomical computations and of course the impossibility of carrying on sun observations in cloudy weather.

The sun shot technique is not cumbersome and basically needs only a few types of equipment:

– a theodolite with adequate precision, which can be the very DIflux theodolite used for magnetic measurements;

– diagonal eyepieces (ocular and microscope) adapted for the theodolite in use so that steep sightings can be carried out (in case of high sun elevation);

– a solar filter fitting on the eyepiece ocular;

– precise time and location (WGS84 latitude/longitude);

– conversion data from UTC to UT1; and

– astronomical tables or software for the sun ephemerides of the current year.

An accuracy of about 1 arcsec in the geodetic north azimuth calculation can be achieved in the best cases, that is if

– timing is better than 0.1 s in UT1;

– the latitude and longitude of the sun shot location is known to better than 1 arcsec on the WGS84 datum;

– the theodolite leveling is achieved to better than 5 arcseconds; and

– the sun shots are performed at the time of sunrise or sunset when the sun has a low elevation.

Leveling of a theodolite with this precision is quite possible, even on a tripod, but frequent level checks and adjustments are required. The errors associated with leveling are given in Fig. 1.

The sun shot technique has notable advantages: it is rather easy to use, does not need much additional equipment, requires the occupation of a single station only and is fast – an experienced observer will not take more than a few minutes of time per sun shot (excluding the calculation by hand).

2 First test setup for semiautomatic sun shots

In our attempts to automate sun shots we tried all kinds of setups. For instance for a rather rough setup we isolated a sun ray as sunlight passing through a pinhole in a black box. This

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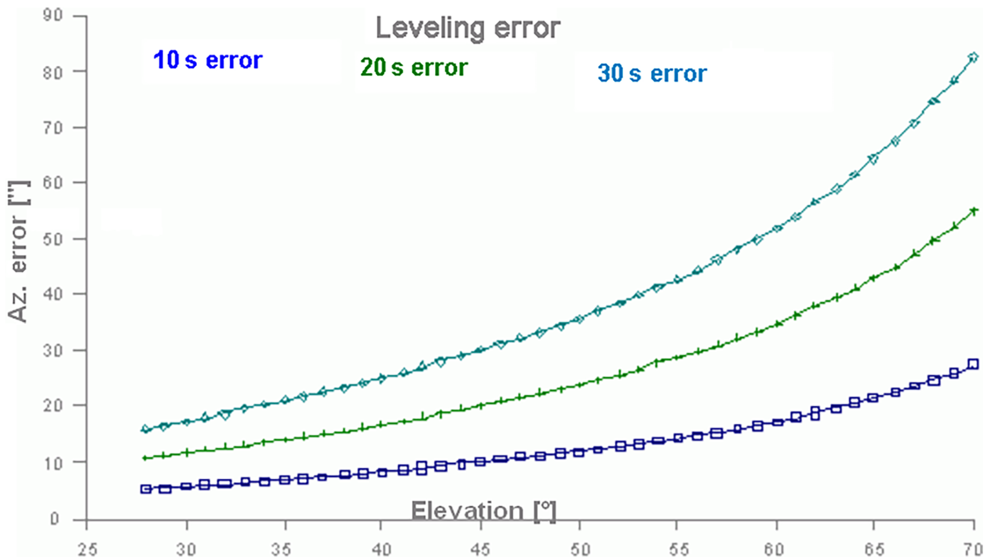

Figure 1. Sun's azimuth error associated with three theodolite's leveling errors vs. the sun's elevation.

ray was reflected back by a shiny sphere to amplify the horizontal angular motions of the ray, which then fell onto a split photocell (two horizontally side-by-side cells). The useful signal was therefore the difference voltage produced by both illuminated photocells. We had to observe this changing signal with the apparent sun motion: the setup pointed to the sun when the difference voltage was zero.

3 Theodolite's telescope with split photocells

Another setup – and the final one – makes use of the theodolite's telescope itself. Indeed the optical magnification is usually about 30× and can be used efficiently by installing the split photocells in front of the ocular side-by-side. Additionally, if the theodolite is of the WIDIF DIflux type pictured in Fig. 2 (Rasson et al., 2016), power and a GPS receiver for precise time and positioning are available. We concluded it was necessary to construct a small mechanical and electronic sun shot add-on able to be slid and fastened on the theodolite's ocular. Electrical and computing power could then be borrowed from the WIDIF itself.

3.1 Mechanical and electronic design

Such an add-on has been designed and manufactured and is displayed in Fig. 3. The sun shot add-on is clamped on the telescope at the ocular end. An articulated cover holding the photocells can be opened so as to leave the ocular accessible for normal telescope pointing with the eye. The cover holds two photocells plus some analogue electronics in front of the ocular lens (when closed) so as to catch the light passing through the telescope and transform it into voltages. The add-on generates "SUM" and "DIFFerence" of the two photocell signals. A small cable runs from the add-on and can be plugged into the WIDIF input–output connector also used for WIDIF battery charging (Fig. 4). The voltages are displayed on the WIDIF LCD screens in numerical form (Fig. 5).

Figure 2. The WIDIF DIflux theodolite packs fluxgate sensor and electronics as well as GPS receiver and a battery on the telescope.

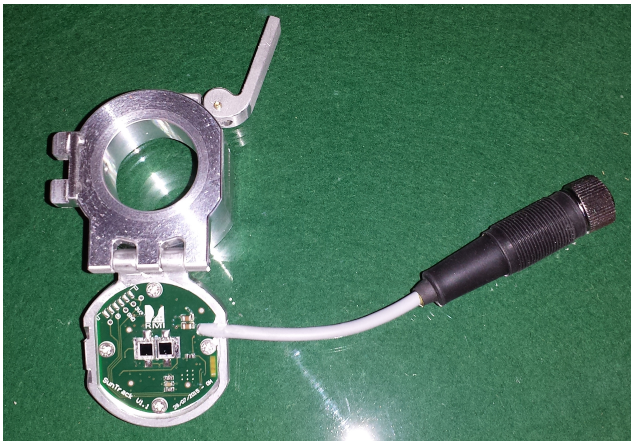

Figure 3. The sun shot add-on is a small mechatronic device fitted to the WIDIF theodolite's telescope ocular and able to precisely determine the sun's direction. Two black photocells serving this purpose can be seen side-by-side on the printed circuit board.

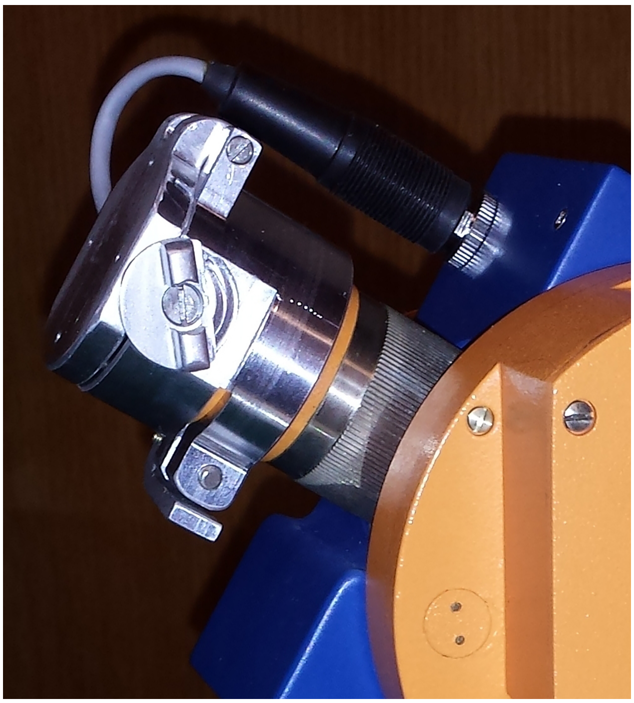

Figure 4. The sun shot add-on mounted on the WIDIF telescope. The device draws its power from the WIDIF battery.

3.2 Sun shot readings from add-on

The procedure for performing a sun shot uses the apparent horizontal motion of the sun to move its sun rays through the telescope. The focused rays will sweep over both cells and stop the clock timer when the difference between the two photocell voltages is zero. But a zero will also exist if no light at all falls on the photocells. Therefore we inspect also the SUM of the photocell voltages.

Figure 5. The photocells sum and difference voltages are displayed on the WIDIF LCD's so as to ascertain the way the cells are illuminated.

If SUM > 600, the sun illuminates both photocells; if DIFF $= 0$ and the telescope axis points to sun at the same time then we have a valid sun shot.

We can now put together a semiautomatic sun shot procedure for a WIDIF theodolite equipped with a sun shot add-on:

1. Point the telescope axis towards the sun with the theodolite's vertical circle (VC) to the right.
2. Use "SUM" signal by maximizing it to center the sun's image on the photocells using the theodolite's horizontal (H) and vertical (V) slow-motion screws.
3. Using H slow-motion screw, point slightly ahead of the sun (to the right of the sun in the Northern Hemisphere) so that "DIFF" is about 100.
4. Start the zero-crossing detector by depressing the service switch on the WIDIF.
5. The Earth rotation moves the sun image on the photocells.
6. When DIFF is 0, zero crossing occurs, the clock is automatically stopped and the UTC time is displayed.
7. Read time and read the horizontal circle (HC).
8. Convert the zero crossing time from UTC to UT1.
9. Compute sun's azimuth.
10. Repeat from point 1 but with the theodolite's VC to the left.

As an example of the capabilities of this sun shot add-on working with a WIDIF theodolite, we performed the measurement of the azimuth of the mark as seen from the D05

UT1=UTC-0.23 s					
	Azimuth of D05 from WS Mark			#CL/CR samples	SD
	°	'	"		"
17/08/2016	170	12	24.9	15	12
25/08/2016	170	12	24.6	8	20
02/09/2016	170	12	24.2	5	13

Figure 6. Some results obtained with the sun shot add-on for azimuth determination. Each azimuth listed is the mean of readings taken with the vertical circle to the left and to the right.

new pillar installed for the DIflux intercomparison session during the Instruments IAGA Workshop in Dourbes during August–September 2016. Results are given in Fig. 6 where the UTC–UT1 correction has been applied. We can appreciate the low dispersion of the results and the rather stable values over time.

4 Special precautions to improve the azimuth accuracy

The observing method calls for observations with VC right and VC left in order to correct, via averaging, for photocell collimation error or unbalanced output voltage from the individual photocells.

The time provided by GPS receivers is usually UTC. The difference between UTC and UT1 is due to Earth rotation irregularity and is kept below 1 s. This translates to a maximum of about 10 arcsec in the sun's azimuth. So for an accuracy beyond that, the correction to UT1 should be applied. It is available on this website: http://maia.usno.navy.mil/ser7/ser7.dat.

Since the WIDIF has a reading resolution of 1 arcmin, which can be interpolated to 0.1 arcmin by eye, it is good practice to preset the index on the HC at existing marks of 1.0 min in step 3. No interpolation is then necessary, eliminating any uncertainty associated with it.

Leveling is quite critical for a sun shot and more so when the sun has high elevation (Fig. 1). Therefore a preferred time for maximizing the accuracy is sunrise or sunset with the sun low over the horizon.

5 At or near the Equator

At or near the Equator the sun has no or little horizontal motion. To obtain a zero crossing from the photocells, it is then necessary to rotate the theodolite around its vertical axis.

Therefore the HC slow-motion screw must be used to manually trigger the zero-crossing detector. This may degrade the accuracy as the operator may overshoot the zero crossing. It may be better to operate manually in those equatorial conditions (see below).

6 Further developments

Provisions have been made to perform the astronomical calculation of the sun's azimuth inside the WIDIF electronics, using the epoch and latitude/longitude information collected by its GPS receiver at the time of the sun shot. The algorithm used for the computation (Bennet, 1980) is the one provided in the Guide for Magnetic Repeat Station (Jankowski and Sucksdorff, 1996; Newitt et al., 1996) and does not need the input from an astronomical almanac. The computation results provided by this algorithm have been checked to be correct within 2 arcsec by comparison with a master program providing sub-arcsecond accuracy (Reda and Andreas, 2003).

The WIDIF will also be upgraded in order to perform the sun shots manually, without the add-on being necessary. The sun is then pointed by eye using a solar filter on the ocular and when the sun is seen centered on the telescope reticle the shot time is logged by depressing the WIDIF service switch. The timing by eye/hand may not be as precise as the one provided by the photocells, except at the Equator.

Data availability. No data sets were used in this article.

Competing interests. The authors declare that they have no conflict of interest.

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