Determining True and Magnetic North on Aerial Photographs

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ABSTRACT: Direction of true and magnetic north on a photo can be determined from measurements of shadow angle if the photo location and sun position are known. The basic methodology with an example of use in Alaska is presented. A computer program written in BASIC is available from the authors.

INTRODUCTION

TERRESTRIAL IMAGE SHADOWS on aerial photos can often be used to solve a number of photo interpretation problems. Object recognition, relative size or height, and photo orientation are some of the uses made from shadow detection and measurement. This paper deals with the latter use, orienting photos with respect to true or magnetic north.

The sampling scheme for the Alaska Integrated Resource Inventory System (LaBau and Schreuder, 1983) often requires orienting photos with respect to magnetic north so that the ground plot sample points and low altitude photos are correctly aligned and to assure that the data measurements in these two phases are consistent.

We know that north of the Tropic of Cancer (23 degrees, 27 minutes), the sun's rays are always inclined toward the Earth from the south, and at any place on the Earth's surface, the sun's rays are from the east prior to local true noon and from the west after this time. Thus, it is possible to orient approximately any photograph if the approximate time and place of photography are known, and precisely if the exact time and place of photography are known (Spurr, 1960).

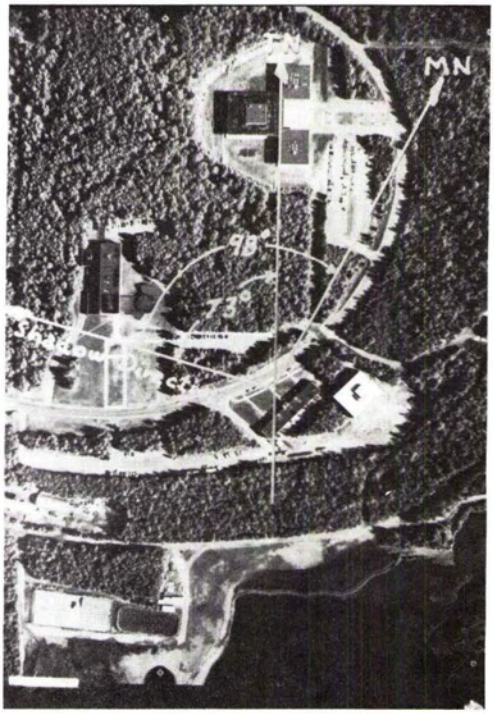

FIG. 1. An aerial photograph of Alaska Pacific University Campus, taken on 19 June 1982 at 10:10 AM Alaska Daylight Savings Time. The photograph is located at 149 degrees 48.2 minutes west longitude and 61 degrees 11.5 minutes north latitude.

THE CALCULATIONS

To obtain accurate estimates of true north for a location, the longitude and latitude of both the photo's location and the sun's zenith (the point on the Earth that is directly below the sun) must be known for the time that the photograph was taken. These longitudes and latitudes can be used to form two points of the spherical triangle on the Earth's surface. The North Pole is used for the third point.

The first step in determining true north from a location requires calculation of the "hour angle" or the difference in longitude between the center of the photograph, as determined from topographical maps, and the sun's longitude (Spurr, 1960). For example, the photo in Figure 1 was exposed at 10:10 on the morning of 19 June 1982, during Alaska Daylight Savings Time, or at a time when the photo location was 8 hours behind Universal Coordinated Time (UCT). Thus, the photo was exposed at 18:10 UCT.

For quick estimates, the longitude of the sun is calculated by adding 1 degree of longitude for every 4 minutes of time past noon at UCT. Thus, the sun's longitude at 10:10 Alaska Daylight Savings time or 18:10 UCT is calculated as follows:

18:10 hrs − 12:00 hours = 6 hrs 10 min

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 6, June 1986, pp. 829–831.

0099-1112/86/5206-829$02.25/0

6 hrs 10 min = 370 min
370 min / 4 min per deg = 92.5 deg longitude

However, the sun does not always pass over the UCT meridian precisely at noon; it is usually either a little ahead or a little behind schedule and the sun's longitude must be corrected for this variation. Solar ephemeris tables give data for correcting this equation of time. The solar ephemeris tables also provide data for calculating the sun's latitude for the date and time given (Table 1).

The true longitude is calculated after computing the true local civil time from true solar time using the time equation for 19 June 1982:

6 hrs 10 min − 1 min 5.6 sec = 6 hrs 9.73 min
6 hrs 9.73 min / 4 min per deg = 92.43 deg longitude
92.43 deg longitude = 92 deg 25.8 min

The sun's apparent declination for 19 June is given as N23 degrees, 24.9 minutes (Table 1). This must be corrected for time since UCT zero hour by the difference in declination for each hour. Thus, the true declination is computed as follows:

Sun's declination for June 19 = 23 deg 24.9 min
UCT time (18 hrs 9.73 min) × 0.04 = 43.6 min
Total declination = 24 deg 8.5 min

Further corrections could be made for refraction and parallax if the barometric pressure and temperature were known. These variables are usually not known in general surveys where aircraft are in the air for several hours and cover large areas with varying barometric pressure gradients. But these variables are of little consequence as the appropriate corrections are quite small, usually less than a few minutes.

This information is used to solve the spherical triangle trigonometric equations associated with the North Pole, the plot location, and the zenith of the sun (Figure 2). The angles of a spherical triangle are related by Napier's Analogies:

$$\mathrm{Tan}[C+A)/2] = \mathrm{Cot}(B/2) * \mathrm{Cos}\,[(z-x)/2] / \mathrm{Cos}[(z+x)/2], \text{ and}$$

$$\mathrm{Tan}[(C-A)/2] = \mathrm{Cot}(B/2) * \mathrm{Sin}[(z-x/2] / \mathrm{Sin}[(z+x)/2].$$

Given that angle B is the absolute value of the longitude of the plot subtracted from the longitude of the sun (and if larger than 180 degrees, then it is also substracted from 360 degrees), arc z is the latitude of the plot subtracted from 90, and arc x is the declination of the sun subtracted from 90, then angle A is calculated by subtracting the arc tangents of the two tangent formulas. Finally, the angle of the shadow from true north is the complement of angle A and is equal to angle A substracted from 180 degrees.

All that remains to be computed is the angle of magnetic north based on the magnetic variation at the plot location. This is either added or subtracted to the shadow angle depending on whether the variation is east or west. In the example presented (Appendix), magnetic variation is 25 degrees, 27.6 minutes east. Thus, the angle to the Magnetic North Pole is 25 degrees, 27.6 minutes greater than the angle to true north.

In our example, the angle from the shadow to true north rounds off to 73 degrees, and the angle from the shadow to magnetic north rounds off to 98 degrees. We use magnetic north in our work because our large inventory units may have six degrees variation or more of magnetic declination, and several areas have strong local magnetic disturbances that can add great confusion to field crews trying to work with true north. Thus, our field crews simply leave their compass set with zero declination and follow the needle.

THE COMPUTER PROGRAM

A computer program written in BASIC for Data General computers* has been developed to solve shadow angle given latitude and longitude of the plot, the date and UCT of day of the photograph,

* Mention of company name or trademark is for the readers' benefit and does not constitute endorsement of a particular product by the U.S. Department of Agriculture over others that may be suitable.

TABLE 1. SOLAR EPHEMERIS FOR 0-HOUR, UNIVERSAL COORDINATED TIME, JUNE 1982*

Day of Month	Sun's Apparent Declination		Diff. in Declin. For 1 Hour	True Sol. Time = LCT + Time Eq	
16	N23 deg	19.7 min	0.09 min	−00 min	26.6 sec
17	N23	21.8	0.07	−00	39.5
18	N23	23.6	0.06	−00	52.6
19	N23	24.9	0.04	−01	05.6
20	N23	25.8	0.02	−01	18.8

*A partial table taken from Keuffel and Esser (1982).

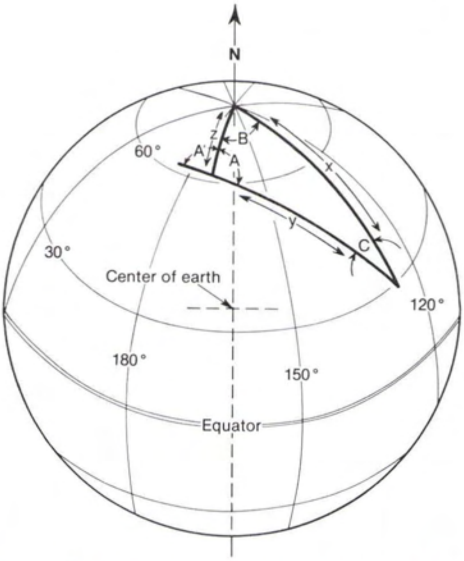

FIG. 2. The spherical triangle is defined by angles at the plot location (*A*), the North Pole (*B*), and the sun's zenith (*C*). Arc *z* is the latitude of the plot subtracted from 90 degrees, arc *x* is the decliniation or latitude of the sun's zenith subtracted from 90 degrees, and arc *y* is the great circle distance between the plot location and the sun's zenith. *A*' is the angle of the shadow from true north.

the solar ephemeris data for the given date, and the magnetic declination at the plot location. Output variables include the angle from the North Pole to the shadow vector and the angle from the Magnetic North Pole to the shadow vector.

Using the program is simply a matter of responding to a sequence of prompts that lead to the desired information. The program is self explanatory in use and even novice computer users should have no problems entering the data and obtaining solutions.

The computer requests the plot latitude and longitude, which in our example is 61 degrees 11.5 minutes latitude and 149 degrees 48.2 minute longitude. Then the user is asked for the date and time of the photograph in UCT(19 June 1982 at 10:10 AM local daylight savings time in our example converts to 18:10 UCT), the solar ephemeris data including the sun's apparent declination (N23 degrees 24.9 minutes), the difference in declination for one hour (0.04 minutes), the true solar time (−01 minutes 5.6 seconds), and the magnetic declination at the plot location (25 degrees 27.6 minutes east).

The computer uses this information to compute the required true and magnetic angles of the shadow direction and displays these angles in degrees, minutes, and seconds of azmiuth.

REFERENCES

Keuffel and Esser Company, 1982. *Solar ephemeris for 1982*. Keuffel and Esser Company, Morristown, N.J. 84 p.

LaBau, V.J., and H.T. Schreuder, 1983. A multi-phase multiresource inventory procedure for assessing renewable natural resources and monitoring change. *Proceedings of the Symposium: Renewable Resource Inventories for Monitoring Change and Trends*. SAF 83-14. August 1983. Corvallis, Ore. pp. 456–459.

Spurr, Stephen H., 1960. *Photogrammetry and photo-interpretation*. 2nd Edition. The Ronald Press Company, New York. 472 p.

(Received and accepted 3 March 1986)

APPENDIX

AN EXAMPLE OF THE INPUT AND OUTPUT FROM THE BASIC PROGRAM*

DETERMINING TRUE AND MAGNETIC NORTH ON AERIAL PHOTOGRAPHS
PHOTO DESCRIPTION: Alaska Pacific University Campus
PHOTO LATITUDE: 61 - 11- 28.000 PHOTO LONGITUDE: 149 - 48 - 10.000
DATE - MM DD YYYY: 6 - 19- 1982
UTC TIME - HH MM: 18 -10

SOLAR EPHERMERIS DATA
TIME EQUATION -1 MINUTES 5.6 SECONDS
SUN'S DECLINATION 23 DEGREES 24.9 MINUTES
SUN'S DECLINATION CHANGE PER HOUR: .04

MAGNETIC VARIATION: E+ W− DEGREES +25 MINUTES 27.6

ANGLE TRUE NORTH TO SHADOW	ANGLE MAGNETIC NORTH TO SHADOW
WEST 72 DEG 57 MIN 46.461 SEC	WEST 98 DEG 6 MIN 13.206 SEC

* A copy of the BASIC computer code may be obtained by writing to the authors.

Errata

A number of errors were found in the September 1985 issue of *PE&RS*. Corrections are listed below by author(s) and page number.

Tilton, Markham, and *Alford*

p. 1264. The ordering of the images in Plate 1 is incorrect. The image at the top of the page labeled (a) is actually (c) and should be shifted to the bottom of the page, and (b) and (c) should be shifted up, becoming (a) and (b), respectively.

p. 1277. In the footnote to Table 11, delete the second sentence.

Benson and *DeGloria*

p. 1284. The first image in Plate 1 should have been labeled "TM Image 5, 4, and 3."

Metzler and *Malila*

p. 1328. In Table 5, "Radiance" should be "Spectral Radiance." The bottom row of the table should read "−0.0150" instead of "−0.1500" in the two places where it appears.

p. 1329. In Table 6. "Radiance" should be "Spectral Radiance." The value for B in the bottom row of the table should be "−0.034" instead of "−0.002," and the last two columns of the bottom row should read "0.002-0.475" and "−0.015-0.485," respectively. The range of values for Band 5, Landsat 4, should be "0.03-1.63."

p. 1329. In the first full paragraph, "0.255 DN," which appears twice, should read "0-255 DN."

Schowengerdt, Archwametry, and *Wrigley*

p. 1404. The third sentence in the first paragraph of the Summary and Conclusions should read "In Figure 9," not "In Figure 8."

Malaret, Bartolucci, Luzano, Anuta, and *McGillem*

p. 1413. Equation (6) should read

$$W_{\overline{SR}} = \Sigma_i \left[\left(\int_{\lambda_L + i\Delta_\lambda}^{\lambda_L + (i+1)\Delta\lambda} 2hc^2 \lambda^{-5} (e^{hc/\lambda kT} - 1)^{-1} d\lambda \right) \overline{SR}_i \right]$$

p. 1413. Equation (9) should read

$$T(K) = 206.127 + 1.0545\ DC - 0.00371\ DC^2 + (6.606 \times 10^{-6})\ DC^3$$

p. 1414. Table 7 was inadvertently not included. It is given below.

TABLE 7. WATER TEMPERATURES DERIVED FROM CALIBRATED TM-s36DATA (°C)

Test Site	Digital Counts	Linear Model	Quadratic Model	Cubic Model	Lookup Table	Ground Truth
CHICAGO						
Foster	121.8	10.9	18.6	18.3	17.5	17.2
Montrose	121.8	10.9	18.6	18.3	17.5	16.1
North Ave.	119.5	9.7	17.4	17.2	16.4	16.7
Oak St.	126.0	13.1	20.8	20.1	19.4	17.8
Calumet	126.1	13.1	20.8	20.2	19.5	17.8
DRESDEN POWER PLANT						
Spillway	142.0	21.5	28.4	26.8	26.4	28.8
Bridge 4	151.0	26.2	32.4	30.3	30.2	32.2

Bryant, Zobrist, Walker, and *Gokhman*

p. 1445. In Table 3, the units of Northing and Easting for the third entry, "Difference," should read "(m)," not "(km)."

Malila

p. 1457. Add the following reference:

Malila, W. A., 1984. Information Theoretic Comparisons of Original and Transformed Data from Landsat MSS and TM. *Proceedings of the Eighteenth International Symposium on Remote Sensing of Environment,* 1–5 October 1985 (Paris, Francis), Environmental Research Institute of Michigan, Ann Arbor, Michigan.