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On the Azimuth Determination

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ABSTRACT

In Geomatics Engineering, the direction of a line should be determined with respect to a reference meridian. A reference meridian can be real or imaginary and its direction is known. The lines being surveyed such as boundaries are angularly tied to this fixed line that joins the north and south poles. Directions are horizontal angles and may be expressed as an azimuth or bearing. Six basic classifications of meridians are astronomic meridian, geodetic meridian, magnetic meridian, geomagnetic meridian, grid meridian, and assumed meridian. This paper covers the fundamental theory and practical applications of the azimuth determination.

1. INTRODUCTION

In surveying, the direction of a line is defined by the horizontal angle between the line and a reference meridian. Azimuths and bearings are used for this purpose. Azimuths are horizontal angles observed clockwise from any reference meridian through a complete circle of 360°. Azimuths in Geomatics Engineering are generally observed from north. On the other hand, there is another way of expressing directions called bearings. Bearings are measured from 0° at either north or south to 90° to either the west or the east. They are measured both clockwise and counterclockwise (Zimmerman, 1995).

The direction of any line is described with respect to a given meridian. Both azimuths and bearings are classified by the meridian to which they are referenced. In other words, they may be geodetic, astronomic, magnetic, grid, 3-D, and assumed. A geodetic meridian and an astronomic meridian go to the CTP (Conventional Terrestrial Pole – the mathematical north pole) and the Earth's instantaneous rotation axis, respectively. The positions of the poles are their mean locations between the period of 1900.0 and 1905.0 for geodetic azimuths. Geodetic azimuths are measured from geodetic north (true north). The geodetic north is accepted by international agreement. Nevertheless, the position of the Earth's poles changes with time owing to the fact that the unsteady motion of the Earth's spin axis. An astronomic azimuth is attained by making astronomical observations. An astronomic meridian passes through the instantaneous position of the Earth's geographic poles (astronomic north and astronomic south). Geodetic meridians slightly differ from astronomic meridians.

Magnetic azimuths and bearings are referenced to lines of the Earth's magnetic field. These lines are magnetic meridians and converge at the magnetic poles. The difference between magnetic north and geodetic north is called magnetic declination. On the other part, grid azimuths are used when working with map projection coordinates. All geodetic meridians converge to the geodetic north (CTP). However, grid meridians are parallel to each other on the mapping projection surface. A specific grid meridian called the central meridian (for example 27°) coincides with the true geodetic meridian. Convergence is the difference between a geodetic azimuth and its corresponding grid azimuth. Convergence on the central meridian is zero.

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As well known, the azimuth of a line is a 2D concept. Thus, a total station instrument can be easily used to observe azimuths. Similarly, the azimuth computations can be performed on a plane cartesian coordinate system. Nevertheless, GPS provides a 3D environment for both surveying and spatial data computations. Therefore, the azimuth of a line can be computed using the local tangent plane components (local geodetic horizon components) of a 3D GPS baseline vector that is defined by geocentric coordinate differences. After having obtained 3D azimuth of a line, the geodetic azimuth can be computed initially. Then, other azimuth computations are carried out (Burkholder, 2008; Wolf and Ghilani, 2008; Van Sickle, 2010).

2. AZIMUTH DETERMINATION METHODS

There are various methods to obtain azimuths. The methods involve the use of some surveying instruments and mathematical calculations.

2.1. Computing Azimuths Using a Total Station

It is needed to know the azimuth of a reference direction to observe the azimuth of any other line using a total station instrument. The azimuth of a reference direction may be determined using a previous survey, a compass, an astronomic observation, GPS observations, or a north-seeking gyrotheodolite. An assumed azimuth may also be used. Initially, the instrument is set up and centered over the station and leveled carefully. A backsight is taken on the target station. The azimuth of line that is between these two stations (instrument station and target station) is then set on the horizontal circle using the keyboard of the instrument. The instrument is turned until it reads zero. The telescope is towards north when the horizontal circle reaches zero. Finally, the telescope is turned clockwise to any point and the direction is read. It is the azimuth from instrument station to the sighted point (Wolf and Ghilani, 2008).

2.2. The 3D Azimuth of a GPS Vector

The 3D azimuth is computed as

$$\alpha_{3D} = \arctan(\Delta e / \Delta n) \qquad (1)$$

where Δe and Δn are the local geodetic horizon coordinate differences of a 3D vector defined by geocentric coordinate differences ($\Delta X, \Delta Y, \Delta Z$). GPS surveying techniques provide precise baseline vector components in the ECEF (Earth Centered Earth Fixed) coordinate system in addition to the geodetic latitude and longitude. The transformation between geocentric differences and local differences may be performed by

$$\begin{bmatrix} \Delta e \\ \Delta n \\ \Delta u \end{bmatrix} = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\varphi\sin\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\varphi \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \qquad (2)$$

where φ and λ are the geodetic latitude and longitude, respectively (Burkholder, 2008).

2.3. Geodetic Azimuth

True north is also called geographic north. There are two types of true north: geodetic true north and astronomic true north.

The azimuth of a geodetic line that is the shortest distance between two points on the ellipsoid surface is called the geodetic azimuth. Geodetic azimuth may be found from the azimuth of the normal section (α_N) or the 3D azimuth (α_{3D}).

The azimuth of the normal section is calculated from α_{3D} by applying the target height correction ($\Delta\alpha_1$);

$$\alpha_N = \alpha_{3D} + \Delta\alpha_1 \qquad (3)$$

$$\Delta\alpha_1 = \frac{\rho h e^2 cos^2\varphi_1}{2N_1(1-e^2)}\left(sin\, 2\alpha_{3D} - \frac{S}{N_1} sin\, \alpha_{3D}\, tan\, \varphi_1\right) \qquad (4)$$

where ρ=206264.806247096355156, h is the ellipsoidal height of target in meters, e^2 is eccentricity squared of the ellipsoid in question, φ_1 is geodetic latitude of the instrument station, N_1 is length of the ellipsoid normal in meters at the instrument station, and S is distance from the instrument station to the target station in meters.

The azimuth of a geodetic line is

$$\alpha_g = \alpha_N + \Delta\alpha_2 \qquad (5)$$

$$\Delta\alpha_2 = -\frac{\rho e^2 S^2}{12N_1^2}\cos^2\varphi_m \sin 2\alpha_N \qquad (6)$$

or

$$\alpha_g = \alpha_{3D} - \frac{\rho e^2 D_{M-M}^2}{12N_1^2}\cos^2\varphi_m \sin(2\alpha_{3D}) \qquad (7)$$

where φ_m is the mean latitude between two points. The mark-to-mark distance is

$$D_{M-M} = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} = \sqrt{\Delta e^2 + \Delta n^2 + \Delta u^2} \qquad (8)$$

where Δu is the third of the local coordinate differences in the user specified topocentric coordinate system (Burkholder, 2008).

2.4. Astronomic Azimuth

The astronomic azimuth (α_A) is computed using the following formula:

$$\alpha_A = \alpha_g + \eta \tan\varphi \qquad (9)$$

where η is the east-west component of the deflection of the vertical (Van Sickle, 2008). Astronomic north varies too little from geodetic north. Typical difference may be a few second of arc. The north for astronomic and geodetic azimuths is related to the spin axis of the Earth and the rotational axis of the reference ellipsoid being used, respectively. As well known, the geodetic azimuth is defined by the mean position of the instantaneous pole during the period 1900 to 1905 (Kuang, 1996).

2.5. Magnetic Azimuth

The magnetic azimuth α_M is

$$\alpha_M = \alpha_g - magnetic\ declination \quad (10)$$

Magnetic declination is the horizontal angle observed from the geodetic meridian to the magnetic meridian (Wolf and Ghilani, 2008). Magnetic declination is caused by the variability of the Earth's magnetic field. Generally, a difference of several degrees between true north and magnetic north occurs (Van Sickle, 2008).

Let us suppose that there is an enormous bar magnet (a fictional dipole) hypothetically at the Earth's center. This powerful bar will generate a geomagnetic field that has a more simple shape than the complex and varied shape of the actual magnetic field. Geomagnetic poles define an axis that intersects the surface of the Earth. Unlike the magnetic poles, the geomagnetic poles are antipodal points. On the other hand, magnetic needles are vertical at the magnetic poles, i.e., the magnetic field is really vertical at magnetic poles. Geomagnetic poles and magnetic poles have different locations. Space physicists and navigators prefer geomagnetic and magnetic poles, respectively.

2.6. Grid Azimuth

Indeed, geodetic north and grid north only coincide at points along the central meridian; everywhere else in the map projection coordinate system there is an angular difference between these two directions. That angular difference is called as the convergence.

The grid azimuth α_{gr} is

$$\alpha_{gr} = \alpha_g - convergence \quad (11)$$

and

$$convergence = (\lambda_{\text{cm}} - \lambda)\varphi \quad (12)$$

where λ_{cm} is the longitude of the central meridian (27° for Izmir), λ is the longitude through the point, and φ is the latitude of the point. The magnetic north position is a natural phenomenon, but grid north is completely artificial (Van Sickle, 2010).

3. NUMERICAL RESULTS

Given the geodetic latitude (φ) and longitude (λ) and geocentric X,Y and Z coordinates (ECEF) of points 1 and 2, the objective is to find the geodetic, magnetic and grid azimuth.

Eq. (7) can be used to compute the azimuth of the geodetic line at point 1. The 3D azimuth should be initially obtained from Eq. (1) to find the geodetic azimuth. The 3D azimuth is 7° 55' 32.'' 4001. Thus, the geodetic azimuth is found as 7° 55' 32.'' 4001.

The magnetic azimuth obtained from Eq. (10) is 7° 55' 32.'' 4001. Magnetic declination that varies with respect to the location and time must be known in order to compute the magnetic azimuth from the geodetic azimuth. Global geomagnetic models such as WMM (World Magnetic Model) and IGRF (International Geomagnetic Reference Field) may be used to determine the magnetic declination. Figure 1 shows the relationship between the true north and the magnetic north.

It is possible to calculate the grid azimuth from point 1 to point 2 using the Eq. (11). The grid azimuth is 7° 55' 32.'' 4001.

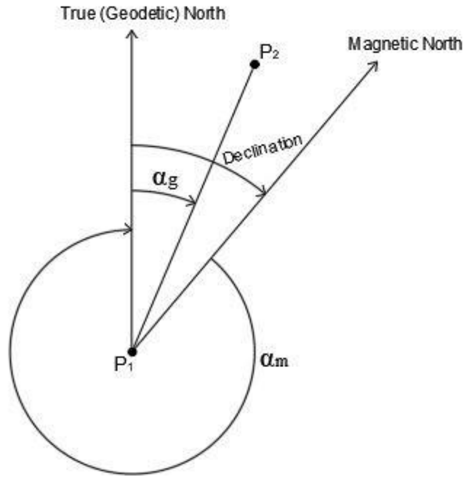

Figure 1. The Geodetic and Magnetic North

The computational results are given in Table 1.

Table 1. Computations

α_{3D}	$3^{\circ}20'49.''\ 272838$
α_g	$3^{\circ}20'49.''\ 272703$
magnetic declination (WMM*)	5°.2733 E
α_M	$358^{\circ}04'25.''\ 39$
convergence	-0.019716914
α_{gr}	$3^{\circ}22'00.''\ 25359371$

*Magnetic declination obtained from IGRF2020 was 5°.2649 E.

4. CONCLUSION

The Earth has more than one north pole. Thus, we need to use various meridians and azimuths (or bearings) to define the direction of lines. A total station or GPS receiver can be used to practically compute the azimuth of all courses of a survey. GPS surveys can provide 3D azimuths. Then, the 3D azimuth being determined can be linked to the geodetic meridian. This procedure yields the geodetic azimuth. Finally, other azimuth types can be obtained by performing simple calculations. The components of the deflection of the vertical are needed for astronomic azimuths. On the other hand, global geomagnetic models are useful to find magnetic azimuths. Grid azimuths are dependent upon the map projection being used. Generally, the astronomic azimuth and the geodetic azimuth are nearly the same. Similarly, the difference between the 3D azimuth and the geodetic azimuth is slight

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