Buletin Geoinformasi, No. 1, Jld.2, ms. 83 - 88, September 1997
© Penerbitan Akademik Fakulti Kejuruteraan & Sains Geoinformasi

GPS for Amateur Astronomer : How Wrong Can You Be?

Mustafa Din Subari
Centre for Geodesy & Geodynamic Studies
Faculty of Geoinformation Science & Engineering
Universiti Teknologi Malaysia
e-mail : m.subari@fksg.utm.my

Abstract

For the purpose of positioning and continuous tracking to celestrial objects using computerised telescope, the geographic position of the telescope to be known to I arcminute accuracy. Quite recently, GPS has been use for telescope positioning. Although GPS derived coordinate is not the geographical coordinate as needed for telescope positioning, further analyses has found that the total error in its derived position amounted to be less than the I arcminute accuracy requirement. Hence, it is O.K. to use GPS for telescope positioning.

1.0 INTRODUCTION

For the purpose of pointing and continuous tracking to celestial objects, the position of the telescope (or the observer) need to be known. Normally in its *curvilinear coordinate* (latitude and longitude), this coordinate would give the geographical location of the telescope on the earth. Quite recently, because of its simplicity and ease of use, Global Positioning System (GPS) receivers has been widely used for telescope positioning. Unfortunately, many was not aware on the significant different between the GPS derived coordinate and the supposedly use geographical coordinate. The two type of coordinates are of different classes. Question then: How wrong can this GPS derived coordinate be?

This paper discusses the difference between the GPS derived coordinate and the geographical coordinate as well as other related coordinate system, and its effect on the accuracy of telescope pointing.

2.0 COORDINATE SYSTEM

For the purpose of locating celestial object using telescope on the earth's surface, several coordinate systems need to be understood, as they are very much related between each other.

Observation to celestial bodies (through its azimuth and altitude) are made in the *Horizon Coordinate System* (or topographic system). This coordinate system is dependent on the location of the observer. In this system, the location of the observer, which is expressed in its 'geographical' latitude and longitude, became the origin of the reference frame (Figure 1). The direction of the zenith of the observer then become the Z-axis, the north direction become the X-axis and the east direction become the Y-axis, completing a left-hand coordinate system, both being defined on the horizontal plane of the system (Mueller, 1977). In this system, an observer on another location will have its own reference frame. An error in the position of the observer, would have disoriented the reference axes of this system by some amount.

In the practical sense, the location of the observer is to be determined through astronomical observation to known celestial bodies such as Catalogued stars. It is then the 'astronomical' position of the observer, rather than geographical. The astronomical coordinate is thus the realization of the geographical coordinate of the observer. However in normal practices, even the astronomical observations are rarely done. Observer's location (or telescope's) are further simplified by using coordinate obtained from maps (Dyer, 1993a), which is NOT geographical nor astronomical but rather 'mapping' coordinate. Obviously, map coordinate is the type of coordinate which is more conveniently accessible by astronomers. Mapping coordinate in turn, are derived from (or rather based on) 'geodetic' coordinate, which are based on a certain reference surface (a fictitious mathematical surface, normally an ellipsoid of revolution) taken to approximate the earth's complex topography.

Geodetic coordinate can be of a local type or a global type. A local geodetic coordinate has a reference ellipsoid that fits the local topography, while a global geodetic coordinate has a reference ellipsoid that fits the whole earth's topography. An example of a local geodetic coordinate system is the Malaysian Revised Triangulation (MRT93) for Malaysia, and a global system is the World Geodetic System (WGS84) which is the reference for GPS. Obviously then, a local geodetic coordinate would have a better approximation to the geographical coordinate of a point in a certain locality.

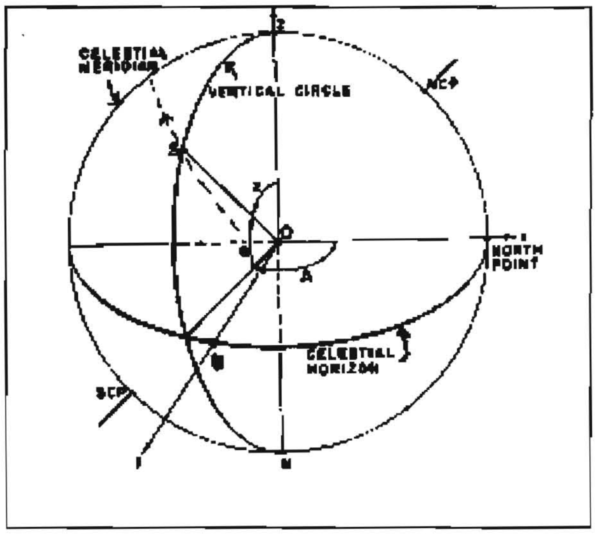

Figure 1: Horizon coordinate system (source: Mueller, 1977)

Differences between astronomic and geodetic coordinate are expressed in the *deflection of vertical*, which essentially gives the amount of the deflection of the normal line from the vertical line, on one point (Bomford, 1980). The normal is a line orthogonal to the ellipsoid surface while the vertical is orthogonal to the geoid. On the point of origin in a geodetic network, this value is normally defined as zero. For Malaysia, this separation is in the range of about several arcseconds.

Differences between two geodetic coordinate systems need to be determine empirically. Normally, several stations which has coordinate in both systems are used and a set of transformation parameters would be obtained. For the case of transforming the MRT93 coordinate to the WGS84 coordinate or vice-versa, normally a 7-parameter transformation is used, known as the Bursa-Wolf 7-parameter transformation, for which values can be obtained from JUPM (1994).

3.0 GPS DERIVED COORDINATE

GPS is a *global* positioning technique which uses a global reference datum. Prior to 1987, the reference datum was the World Geodetic System (WGS72). Currently it is the WGS84. It is thus the datum in which all GPS positioning information is referred to, by virtue of being the reference system of the Broadcast Ephemeris (i.e., the datum in which the position of the satellite is given). WGS84 is an Earth

Centered Earth-Fixed (ECEF) Cartesian Coordinate System with (Rizos, 1996):

- Its origin at the earth's centre of mass (i.e., the geocentre is the physical point about which the satellite orbits)
- Its "Z-axis" is aligned parallel to the direction of the Conventional Terrestrial Pole (CTP) for polar motion, as originally defined by the Bureau International de l'Heure (BIH), and since 1989 by the International Earth Rotation Service (IERS).
- Its "X-axis" is the intersection of the WGS84 Reference Meridian Plane and the plane of the CTP Equator (the Reference Meridian being parallel to the Zero Meridian defined by BIH/IERS).
- Its "Y-axis" completes a right-handed, earth-centered, earth-fixed orthogonal coordinate system, measured in the plane of the CTP Equator, 90° east of the X-axis.

3.1 GPS positioning accuracy

GPS is a *satellite-based* positioning system. A GPS user would observed signal transmitted by the satellites via a GPS receiver, to compute their position, utilising the known position of the satellites.

For a 3-D position determination purposes (XYZ or latitude, longitude and height), at least 3 satellites are needed (for three range measurements), but normally, four satellites are observed in view of solving also the receiver clock error, which otherwise would have greatly effected the accuracy of the positioning (Figure 2).

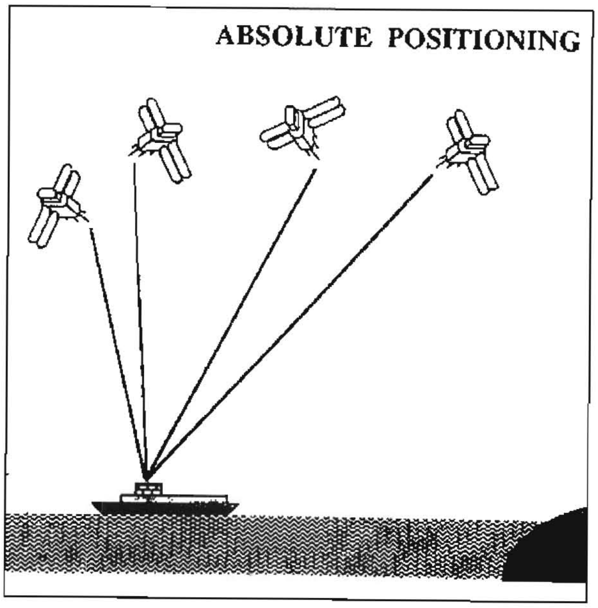

Figure 2: GPS positioning - absolute mode.

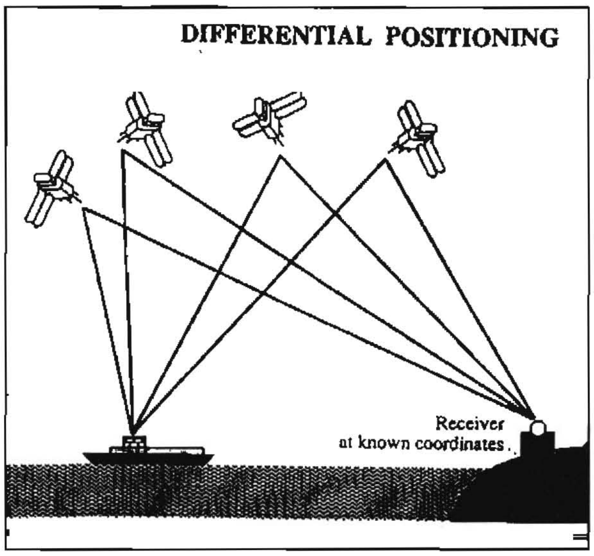

Figure 3: GPS positioning - relative mode.

As in any positioning techniques or devices, GPS derived position is also polluted by many error sources as well as biases in the measurements. These errors and biases are those induced by the GPS satellite, the path of the signal propagation and the receiver on the ground. It includes; satellite clock, satellite ephemeris, an intentionally introduced Selective Availability, ionospheric and tropospheric delay, signal multipath, receiver clock and receiver noise. In the absolute positioning technique, these errors and biases would have affected the positioning accuracy, while in a relative positioning technique (Figure 3), most of these errors and biases would be common for the two stations and canceled out in the differencing technique employed in the data processing. This resulted in a very precise 'relative' position. The relative or differential positioning technique is widely employed for surveying applications.

There are two positioning services given by GPS namely; the Precise Positioning Service (PPS) which is only meant for the utilization of the US military and its allies; and the Standard Positioning Service (SPS), which is for public use. PPS on overall gives a tenthfold better positioning accuracy than SPS.

Currently, since the declaration of its Full Operational Capability (FOC) in July 1995, GPS through SPS, in the absolute mode, is giving 100m horizontal and 156m vertical positioning accuracy at 95% reliability level, and 300m horizontal and 500m vertical positioning accuracy at 99.99% reliability level (Johns, et al., 1994). Relative positioning mode on the other hand would give far off better accuracy, about 2-5 m horizontal and 5-10m vertical.

4.0 TELESCOPE POINTING ACCURACY

Most eye-piece for telescope does not have *cross-hair* for precise pointing purposes as in *theodolite* (an angle measuring device used mainly by surveyors). Thus, the pointing accuracy is only defined by the field of coverage, or *field-of-view* of the telescope, which in turn, depend on the type of eye-piece and the magnification being used for the telescope (Dyer, 1993b), as depicted in Figure 4.

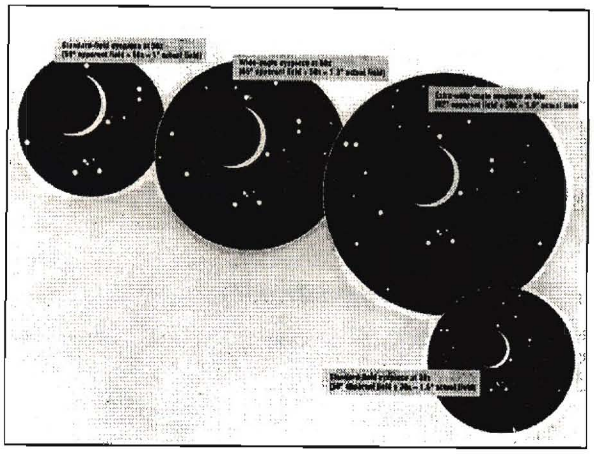

Figure 4: Field of view of telescope: Different eye-piece at different magnification (Source: Dyer, 1993b.)

For manually operated telescope, the position of the location is not necessary. The telescope only need to be oriented to the North direction, normally pointed to Polaris or with the aid of a compass (which gives a Magnetic North direction, instead of the True North). Then a known celestial object (with known RA and declination) is tracked, and necessary settings in the RA and declination circle of the telescope are applied.

With computerised telescope, apart from the North direction orientation, for automatic tracking purposes, the telescope position (geographic latitude and longitude) need to be known at least to the nearest arcminute (Dyer, 1993a) (which translates to about 1.8 km in distance radius). Normally, this position is taken from road atlas or topographic maps.

With this accuracy setting, Dyer (1993a) reported that *"using the 26 mm standard eye-piece which gives 0.5 degrees field of view, it almost always ended up within the field of view, sometimes off-centered by an acceptable 10 arcminutes or less, except for objects near the poles, where the search ended at 12-20 arcminutes or just outside the field of view"*.

Hence, 1 arcminute accuracy can be seen as a moderate requirement for 'mobile' telescope positioning (both in latitude and longitude). For a higher accuracy requirement, e.g., telescope permanently located in a mini observatory, a fraction of that would then be necessary, maybe 0.1 - 0.5 arcminute.

5.0 GPS FOR TELESCOPE POSITIONING

When using GPS derived coordinate for telescope positioning, the total coordinate error of the position, is a summation of errors which includes; error in GPS positioning, and errors accounting the differences between the coordinate systems.

Position error = GPS positioning error + 'difference of coordinate system' error

For Peninsular Malaysia, mapping coordinate are based on the Malaysian Revised Triangulation 1993 (MRT93) coordinate system, hence the basis for making topographic maps. Fortunately, differences between WGS84 coordinates and MRT93 coordinates are within several arcseconds (JUPM, 1994). An example of this can be seen for the three stations cited in Table 1.

Table 1: Differences between MRT93 and WGS84 coordinate

Point	Latitude Diffn. (")	Longitude Diffn. (")
Pengeli, JOHOR	0.274	6.135
K.Setar, KEDAH	1.428	4.745
P.Putih, KELANTAN	1.423	5.587

Considering that the standard positioning error in GPS is about 100 m (or 3-4 arcsecond in curvilinear distance), plus about less than 10 arcsecond for the difference coordinate system induced error, the maximum position error would be less than 15 arcsecond, definitely still within the 1 arcminute accuracy requirement!.

For a higher positioning accuracy requirement (less than 0.1 arcminute), necessary transformation from the WGS84 coordinate to the local geodetic coordinate is required. For Malaysian scenario, WGS84 coordinate need to be transformed to the MRT93 coordinate using the Bursa-Wolf 7-parameter transformation technique (Ibid, 1994). This transformation would give position accuracy of about several arcsecond.

6.0 CONCLUSIONS

It is O.K. to use GPS for telescope positioning. The maximum error in using the GPS derived coordinate for telescope positioning, for both latitude and longitude, is well under the 1 arcminute accuracy required. For better accuracy requirement, such as to position permanently located telescope as in a mini observatory, astronomical coordinate which would give several arcsecond accuracy, need to be observe. Otherwise, WGS84 derived coordinate should be transformed to MRT93 coordinate (in the Malaysian scenario), using for example, the Bursa-Wolf 7-parameter transformation procedure.

REFERENCES

Bomford, G., 1980. Geodesy, Clarendon Press, Oxford. 855pp.

Dyer, A., 1993a. Using Meade's LX200, Astronomy, July, pp.66-77.

Dyer, A., 1993b. Choosing eyepieces : A buyer's guide. Astronomy, June, pp. 56-65.

Johns, J.C., and R. Conley, 1994. A summary of GPS SPS performance as observed by the FAA's GPS Performance Analysis Network, Proceedings of the ION GPS-94, Seventh International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt City, Utah, September 20-23, pp. 1117-1125.

JUPM, 1994. *GPS derived coordinate* , Geodesy Unit, Topography Section, Jabatan Ukur dan Pemetaan Negara Malaysia.

Mueller, I.I., 1977. *Spherical and practical astronomy as applied to geodesy.* Frederick Ungar Publishing Co., New York, 615pp.

Rizos, C., 1996. *Principles and practice of GPS surveying*. Lecture Note. Department of Geomatic Engineering, the University of New South Wales, Australia.

Taher, H. 1990. Unsur-unsur astronomi praktik untuk kegunaan ukur tanah, Unit Penerbitan Akademik, Universiti Teknologi Malaysia, 261 pp.