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Unscrambling Geodesy for Practical Surveying

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ABSTRACT

The study of geodesy continues to be a necessary task for students of surveying, but understanding its complex concepts and its extensive theoretical detail can be confusing. Practising surveyors who do not undertake sizable geodetic surveys may feel that they never get on top of the subject, and they may be left with concerns that there are aspects of geodesy which they do not fully understand, but which they should know about for occasional use in their practical work. The argument in this paper is that it does not have to be like this. Many geodetic matters can be eliminated as being of little consequence in most practical surveying, and the explanations of the remaining necessary and crucial topics can be simplified to an easily digested level. In order to explain this concept, the paper enumerates the superfluous topics and briefly itemises crucial geodetic topics.

KEYWORDS: *Geodesy, learning, education, practical surveying*.

1 INTRODUCTION

The widespread use of satellite positioning techniques and the availability of software suited to spatial data presentation seem to have expanded the uses of spatial information to diverse parts of the community, not only for engineering and construction, but also for planning, emergency services assistance and so on. But it is still surveyors who have the detailed understanding of the collection of spatial data, coupled with a capability to carry out 3-dimensional spatial data coordination *over large areas and to high accuracy*. This is made possible by their knowledge of the use of geodesy. But geodesy can be a difficult and confusing subject to master. The concern expressed in this paper is that there is a need to help students in university or other courses in surveying to identify and understand those geodetic matters that are crucial to practical surveying. They need to get geodesy into perspective, supplementing that outline with the more detailed coverage which is provided in lectures, text and reference books on geodesy and in technical manuals on geodetic networks and map grids when it is needed. It may also be true that there are practicing surveyors who are not yet on top of all of geodesy's confusing aspects, and who could benefit, not so much from a simplistic set of practical instructions, but from an explanation of the geodetic matters which are crucial for practical surveying, as plainly as possible and as briefly as possible.

2 ASSUMPTIONS

Surveyors who carry out surveys over areas which are a bit larger than normal – perhaps for roads, railways, pipelines, transmission lines or large mine sites – will face geodetic complications. It is also necessary to recognise that even smaller engineering, topographic and other surveys are usually tied into a coordinate system that covers a region, state, country or continent, and those connections also involve geodetic issues. One of the particular challenges for surveyors can be to discover which parts of geodesy are most important to them in practice. This paper enumerates some tactics that can be adopted to help unravel geodesy and then outlines the geodetic issues that are essential for practical surveying. The paper is brief, as if to emphasise the limited amount of geodesy that is crucial.

We can look at the demand for geodesy by considering the geodetic issues which might arise in cases where surveys extend for distances up to about 25 km. In these surveys, it could be assumed that surveyors would use total stations to measure angles and distances, but that they may, occasionally, face angle and/or distance measurements over lines up to 10 km long. It could also be assumed that satellite-based measurement would be undertaken over various distances, and that the required accuracy in these surveys would be at least 1:100,000, with the required accuracy for angles, directions, bearings and azimuths at a corresponding accuracy of 2”. Specialised geodetic control surveys and very-high-precision engineering surveys, which are likely to be of higher accuracies and/or over larger areas, need not be a target of such an explanation of geodesy for most surveyors.

3 TACTICS TO SIMPLIFY GEODESY

Some tactics can be adopted to help surveyors understand crucial geodesy:

1) *A lot of geodetic theory can simply be ignored.* Not all geodetic theory is crucial to surveyors in practice: surveyors need a knowledge of *geodetic surveying*, not a knowledge of geodetic *science*. Matters such as geoid determination are important elements of geodesy courses for surveyors to give them a broad introduction to the geodetic world, but details are not crucial for most practical surveying. Lectures, textbooks and technical manuals provide details of geodetic theory for those who need it.

2) *Not only can a lot of geodetic science be avoided, but a lot of practical geodetic surveying that applies only to very precise geodetic control and engineering networks can also be avoided.* It usually applies to large areas, based on measurements over long distances, the sort of specialised surveying that does not apply to the more common surveys which fit the scenario outlined above.

3) *A lot of mathematics can be avoided.* Geodetic calculations must be based on an ellipsoidal shape, to avoid the possibility of losing accuracy, and the mathematics of an ellipsoid are very complicated – far more complicated than for a sphere – and this means that a lot of geodesy is really just mathematics. For example, Vincenty’s formulae, which were developed in the 1970s to permit calculations of azimuth and distance between two points given their latitudes and longitudes, is presented over two pages in the Geocentric Datum of Australia 2020 technical manual (ICSM, 2018). But surveyors only need to have a feel for the mathematics and understand what it can accomplish. Mathematical details are available in geodesy textbooks, technical manuals and formal course lectures when needed.

4) *Most geodetic effects that are relevant to surveyors would arise even if the earth was spherical. So, despite the emphasis on the use of an ellipsoidal shape to represent the earth, the earth can almost always be thought of as a sphere when considering geodetic problems!* Difficult concepts such as meridian convergence, and all the Universal Transverse Mercator (UTM) issues of scale factor, grid convergence and arc-to-chord corrections, arise whether

the earth is spherical or ellipsoidal. The ellipsoid shape obstructs simple computing – but its use should not be a barrier to an understanding of geodesy.

5) *A careful distinction must be made between the use of a curved ellipsoidal datum and the use of a map projection.* The use of map projections means that surveyors need to understand calculations on both the curved earth surface and the map projection, so they have to cope with two coordinate systems: the geodetic system based on the curved earth and the map grid system, with two types of north, two types of bearings, two types of distances, two types of coordinates, and so on.

On the other hand, there are a few things which are essential. The most confusing things are the need for and the use of the following matters. The first group, which affects azimuths and bearings, is the hardest:
a) Meridian convergence.
b) Arc-to-chord corrections.
c) Grid convergence.

The second group, which affects distances, is not quite as difficult:
d) Height corrections to distances on the ellipsoid.
e) Scale factor on the UTM grid.

Typical magnitudes of geodetic effects are useful to know. It can be hard to identify which geodetic phenomena are large enough to be relevant to surveys, so surveyors need guidance about the magnitude of geodetic effects, even to see when the effects are small or negligible. The need for informative magnitudes applies especially to the items (a) to (e) above!

4 THE GEODETIC MATTERS WHICH ARE CRUCIAL FOR SURVEYING

Given the tactics outlined in section 3, it is then possible to summarise those geodetic considerations which are crucial to practical surveying:

1) Geodetic datums: The surveyor does not need to understand in detail how a geodetic coordinate system is established. However, it is useful to understand a small amount of the theory about the ellipsoidal coordinate system – the geodetic datum – that surveyors tie into.

2) Calculations on the geodetic datum: Once a geodetic datum has been established, surveyors can calculate the coordinates of points in their surveys on that ellipsoidal shape, which is a smooth mathematical representation of the earth. A few matters need to be understood:
   - Surveyors measures angles and distances on the uneven topographic surface of the earth, so it is necessary for field measurements to be converted from values on the physical earth to values on the ellipsoidal datum. However, for the types of surveys being considered here, it turns out that angles in the field can be used on the ellipsoid without alteration, and the only correction that is usually significant is to reduce distances for the height above or below the ellipsoid.
   - Another aspect of using the ellipsoid that surveyors need to appreciate is the way that a straight line continuously changes its azimuth. Meridian convergence can be confusing.
   - Calculating on the geodetic datum demands enormously complicated mathematics involving the ellipsoidal shape, but the surveyor does not need a detailed understanding.

3) Using the UTM map grid: In practice, surveyors are more likely to carry out survey calculations on a map grid than on the ellipsoidal datum. It is important to understand that any map grid is a projection of shapes, angles, distances, positions etc. from the ellipsoid surface: *the map grid is not a direct projection from the physical earth. That is, a map projection is not possible without a geodetic datum*. (And therefore, whether a survey is calculated on the ellipsoid or on the map grid, the use of the ellipsoidal datum is best explained before the use of the map grid.) However, if the map grid is to be used, it is necessary to understand the crucial features of the widely-used UTM projection. Calculating on the UTM map grid is usually easier than using the ellipsoidal datum, especially as, over short distances (taken as meaning lines up to only one kilometre, to be safe), straight lines on the earth (or on the ellipsoid, really) can be regarded as also being straight on the map grid, and the projection is conformal. For the surveyor using short lines, the main matters to be appreciated are just the following:
    - Applying the scale factor is essential for all lines, short or long, everywhere.
    - The transfer of angles as they are observed in the field onto the UTM grid, and the calculation of the grid bearings of lines, are easy matters.
    - The difference between azimuth and UTM bearing is important but easy to understand.

    These matters look easy, but, as lines get longer, *each* of these three matters gets complicated. *Each* one demands understanding in some detail of how to cope with the curvature caused by long lines. Most significantly, surveyors need to understand how they can obtain the grid bearings which they need in the field. Arc-to-chord corrections and grid convergence need to be explained.

4) Surveys of heights: Understanding heights in geodesy should not cause much difficulty. The determination of the heights of any points, by levelling or notably by satellite methods, should normally involve connections to benchmarks whose heights are known on the height datum, the authorised vertical control network.

5 CONCLUDING REMARKS

While a knowledge of geodesy is essential to surveyors, for many surveyors only a limited number of geodetic topics is crucial. This paper has attempted to point out what can be omitted and what is crucial, without denying the benefits of more extensive knowledge of the subject. The role of lectures, text and reference books on geodesy and technical manuals on geodetic networks and map grids is to provide the complex and detailed theoretical coverage of geodesy, so a simplified overview, which uses the tactics outlined in section 3 and which provides an outline like that in section 4, may be difficult for students to obtain.

REFERENCES

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