

SATELLITE POSITIONING THE SURVEYOR'S OPERATIONAL REQUIREMENT

by Lt.-Col. W.J. PREISS, MSc, MA, FRAS, ARICS, RE ^(*)^(**)

This paper was originally presented at the NAV 84 Conference on Global Civil Satellite Navigation Systems held in London in May 1984, and is reproduced with the kind permission of the organizers, the Royal Institute of Navigation, U.K.

ABSTRACT

The object of this paper is to develop surveyors' operational requirements for satellite positioning systems for the measurement of coordinates at positions which are inaccessible by conventional surveying methods. The paper briefly reviews positioning requirements with some comments on necessary accuracies, difficulties and technique options. Further developments to the existing capabilities of the Transit satellite positioning system are then suggested and the paper ends with some comments on the way that the surveying profession itself might develop in order to meet the needs of this relatively new surveying method.

INTRODUCTION

Much has been said in many places about the so-called technological explosion, and the surveyor who is concerned with determining position has not escaped the aftermath. The pace of development continues to accelerate, and, having now had a taste of practical positioning using satellite means, it is appropriate to look to the future.

The opportunity to discuss surveyors' requirements from the surveyor's viewpoint is welcome for another reason. Although it may be controversial to say so, surveyors' opportunities to influence equipment manufacturers in their instrument designs have often been limited. With the long-lasting classical instruments,

(*) Operations Division, HQ Afnorth, BFPO 50, BFPO London, England.

(**) *Author's note* : The opinions expressed in this paper are those of the author alone and do not reflect the policies of the Ministry of Defence, Directorate of Military Survey.

this has perhaps not been too important. It is suggested, however, that it is very necessary that the surveyor has a hand in specifying the capabilities of high-cost, high-technology equipment which is then expected to be overtaken by even higher capability devices within a relatively short period of time.

With these points in mind, therefore, the object of this paper is to develop a Land Surveyor's operational requirement for a positioning system to satisfy his need to provide coordinates at points which cannot be accessed by conventional classical survey means for reasons either of cost or practicality.

A brief review of survey positioning requirements will be given, together with comments on the accuracies which may be needed. The review will continue with some notes on difficulties and on survey technique options. These will be used to argue that satellite-based methods are attractive, although there are significant penalties. On this basis, the paper will then be able to develop the system capabilities which should be sought in future satellite-based systems.

THE POSITIONING REQUIREMENT

In the context of this paper, the positioning requirement is such that conventional triangulation/traversing techniques cannot be used, either because there is no available intervisibility (i.e. offshore, or dense afforestation) or because the nearest existing control is very far away. Nevertheless, coordinate control in these circumstances is often necessary, and some examples of its uses are listed briefly below :

— Conventional mapping control for new medium and small scales mapping (i.e. 1: 50 000 and smaller) in undeveloped areas can be established with considerably less trouble if extensive conventional triangulation schemes can be avoided.

— In the offshore earth resources exploitation environment, the positions of structures out of sight of land are needed for licensing, exploration, unitisation (subdividing the extractable resources between sharing operators), engineering, and for locating local navigation aids, to name but the most obvious purposes.

As usual, the accuracy with which positions need to be determined is derived from the purpose for which the positions are to be used. It is, however, often the case that a careful judgement of these purposes will lead to a variety of accuracy specifications. Certain of the uses will demand a defined absolute accuracy, while others may require perhaps a considerably tighter relative accuracy.

The techniques for achieving relative and absolute accuracy, perhaps at differing standards, can be conflicting, especially when historical and legal influences demand that the results are presented with respect to inconvenient and perhaps distorted datum systems.

In the experience of the author, it has often been difficult to arrive at a clear statement of accuracy requirements, except in the context of conventional mapping. Offshore accuracy requirements have appeared to range from some 20-50 metres with reliable repeatability during exploration phases down to 1 metre (1 sigma) absolute for permanent structure positions and 0.2 metre (1 sigma) relative for

seabed pipeline applications [1]. Meanwhile [2] quotes the accuracies with respect to the required legal datum system which were considered achievable in the North Sea in 1980, and it is noted that these are significantly less than the 1 metre and 0.2 metre figures quoted above.

TECHNIQUE OPTIONS

The Transit satellite navigation system is the only hardware option currently in wide use, and, as such, needs little introduction. It is to be remembered that it involves the employment of Doppler techniques to monitor transmitted messages from the satellite which include details of its orbit. These messages and the Doppler observations are subsequently processed to develop the eventual position. The continued availability of Transit is dependent on the willingness of the USA (currently) to continue to track the satellites and update the satellites' ephemeris memories.

Transit has been in operation for a number of years, and is to be superseded by the Global Positioning System (GPS). As with Transit, the American GPS system is designed primarily to fulfil defence requirements, and its eventual availability to non-defence users remains, at the time of writing, to be decided. All that is absolutely clear is that once GPS is fully operational, continued USA support for Transit cannot be guaranteed.

Meanwhile, scientific developments of satellite laser ranging systems have been in hand for a number of years, and absolute accuracies in the region of the 0.2 metre mentioned earlier are achievable. However, the equipment involved can hardly be considered to be portable in the sense of the familiar geodetic Transit receivers, and until or unless it becomes so, laser ranging cannot be classed as a surveyor's positioning tool. It is appropriate to note that similar remarks on practicality can be applied to radio interferometry techniques using stellar sources. The possibility that such techniques will become sufficiently miniaturised in future should not, however, be discounted, and their attraction is in their potential for high absolute accuracy.

In addition to the hardware techniques options briefly discussed above, it is necessary to review the available postprocessing choices. Naturally, different techniques alter fieldwork requirements, and the existence of these alternatives is important because of the different accuracies which have been claimed.

Essentially, Transit observation techniques can be grouped in two modes, as single point observations, or as multi-station observations. With the single point observations, the user depends for his results entirely upon decoding the satellite ephemeris from the transmitted signals. Resultant accuracy follows from assessing the accuracy of the ephemeris and the error budget of the observing system. The eventual output coordinates are then in the satellite datum system as explained in [2], and accuracy should be thought of as "absolute" in these worldwide datum systems.

With multi-station simultaneous observations, computational techniques are available to refine the estimation of the satellite's instantaneous position, therefore

providing a potentially more accurate result. It is stressed, however, that these better results are related to the locations at which simultaneous observations have been made, and it is better to think of potentially high *relative* accuracy and questionable *absolute* accuracy.

THE ATTRACTION OF SATELLITE METHODS

Given the positioning requirement set out earlier, the attraction of using satellite positioning systems in the offshore environment is obvious. There is no alternative at the levels of accuracy available. Satellite positioning is also an attractive option for onshore control surveys on grounds of economy, in that the alternative conventional ground triangulation surveys involve much larger resources of more skilled manpower for possibly protracted periods of time. The completion of such conventional terrestrial surveys is also much affected by the vagaries of weather conditions, while satellite observations are effectively weather independent.

Specifically, a single point satellite fixation can be achieved in some three to eight days of station occupation at the cost of no more than one or two less skilled operators, their logistic support, and a single satellite receiver.

The other significant attraction of satellite positioning methods compared to conventional procedures is that of station siting. Satellite observing sites can be located anywhere that provides a satisfactory observing environment. Thus, the satellite surveyor is not necessarily constrained to observe at stations which are often difficult to occupy and yet have to be used for conventional triangulation intervisibility purposes.

DIFFICULTIES WHEN USING SATELLITE SYSTEMS

Whichever of the current satellite observing techniques is used for positioning purposes, the provision of the resulting coordinates depends upon a knowledge of the instantaneous orbital position of the observed satellite. As said before, the orbit of the satellite is produced by USA agencies and is thus completely uncontrolled by the surveyor himself. Meanwhile, the computations of results are performed either aboard the microprocessor contained within the receiver or subsequently using more sophisticated software packages on larger computers. Due to their sophistication and complexity, it is again argued that post-processing is largely out of the surveyor's control. Reference is directed to [2] which reported on evidence to suggest that outcoming positions vary slightly according to the software used.

It is thus inevitable that satellite derived positions disagree with results previously determined by other means, and the discrepancies have been the subject

of considerable technical literature, see for example [3], [4] and [5]. It is generally accepted that current satellite Doppler derived single point positions include errors in scale and in longitude orientation compared to the absolute truth. Thereafter, classical survey datums, which were often defined long ago by adopting coordinates for local origins, also vary systematically from the truth. Nevertheless, particularly in offshore applications, accurate positions need to be provided with respect to such local datum systems. Thus, having corrected the satellite observations, it is necessary then to corrupt them to fit into the local environment. Further corruption may be needed in circumstances where, as in the North Sea area, the local datum system, in which licensing is defined, is known to be significantly distorted. (For example, it is known that the European Datum 1950 in Great Britain contains a scale error of three parts per million or so, since it is based on the Ordnance Survey 1970 Scientific Triangulation Readjustment [6]).

There are also difficulties and penalties to be incurred in observing procedures using satellite receivers. The most significant of these is that of station siting. On land, the surveyor is able to select a site for the satellite antenna which will be propitious for the receipt of clear signals which are as uncontaminated as possible by reflections from the surrounding terrain and culture. (This problem is analogous to the well known "ground swing" phenomenon, which affects terrestrial electronic distance measurements). At offshore sites, however, not only is antenna site selection severely limited by the size of the platform, but structure operators will almost invariably treat that antenna as a highly unwelcome visitor! More often than not, the antenna site on an offshore platform will be poor with regard to reflected signals, resulting in "noisy" observations which in turn culminate in degradation of the accuracy of the eventual results.

OPERATIONAL REQUIREMENT FOR SATELLITE SYSTEMS

It is now possible to develop a statement of the capabilities which surveyors might seek in a future satellite positioning system. It is not considered necessary to labour or even state the obvious points of portability, reliability and all-weather survival capability. The intention is to highlight those system areas which would benefit from improvement.

Firstly, considering the receiver equipment itself, the surveyor needs to be able to establish a site unaided and then to be able to leave the equipment unattended while he performs the all-important terrestrial surveying activities of station description and documentation, and connection to local features to enable the station to be subsequently recovered. Meanwhile, the receiver needs to enable the surveyor to easily monitor performance and accuracy achievement so that the decision can be made and justified as to whether enough satellite passes have been recorded.

Secondly, it is considered important that the equipment provides the surveyor with some aid in site selection. The author is not knowledgeable on the subject of signal propagation or reflection, nor on antenna design. However, it is suggested that a means may be found to enable the "reflection signature" of the local horizon

to be measured. This information could then perhaps be used to control the receiver to eliminate or correct satellite observations, which are likely to be corrupted.

Thirdly, the surveyor's accuracy requirements demand that the satellite ephemeris used in post-processing is as accurate as possible. This means that a predictive ephemeris as is currently transmitted by the Transit satellites is unlikely to be satisfactory unless the intervals between predictions are kept very short. Conversely, an accurate a posteriori ephemeris computed from tracking observations at known stations will, even if it can be obtained by non-defence users, inevitably cause delays in the production of results, and the surveyor would have limited means at his disposal to help him decide when he has recorded sufficient passes.

Whichever way the satellite ephemeris is made available, there is a clear requirement for the surveyor to be able to rely absolutely on the integrity of processed results. Surveyors' confidence would be enhanced by the publication of detailed texts, which give a clear definition of the methods used by software packages to process the observations. It is, for example, necessary to know what corrections are applied, how, and in what sequence, in order to be able to make a realistic judgement of end result accuracy. In order to assist with this, it is considered that geodetic satellite receiver manufacturers, as a part of their marketing/after-sales policy, should be expected to retain the services of experienced and professionally qualified surveyors to advise in detail on all aspects of satellite surveys.

It is considered that satellite receivers should not be constructed with a built-in facility to output near-real-time results related to a survey datum of user choice. For one thing, coordinate transformation from satellite to local datum is a trivial computation once conversion parameters are known. The important point, however, is that, based on past experience, estimates of conversion parameters are improved as time goes by. It is better for the surveyor to apply transformations himself, thus implicitly committing himself to submit records of having done so, rather than to rely on the manufacturer to have supplied the correct transformations for the job in hand and for the epoch of the observations.

The discussion in this paper has centred around satellite systems which provide survey positions at surveying accuracies. No current single point satellite observing system will provide azimuth. However, the surveyor's requirement is usually for position and orientation together. Therefore, having answered the broad questions relating to positioning itself, it is suggested that a satellite receiver system which additionally offers azimuth output of commensurate repeatability would have considerable attraction.

CONCLUSION

It is concluded, in summary, that the requirement for satellite survey positioning systems suggests that the following developments are needed :

- automatic operation and progress quality assessment;
- assistance to site selection and optimisation, vide reflected signals;

- as accurate a satellite ephemeris as possible;
- in-depth details of computing methods, backed by qualified professional surveyors in the employ of manufacturers to provide users with technical satellite surveying advice;
- no receiver should have built-in datum change parameters;
- combination of positioning with an azimuth determining capability “in the same box”.

Meanwhile, within the surveying profession, it is considered that there is a case for some development as well.

Clearly, surveyor education needs to continue to ensure that surveyors are equipped to be able to handle the problems associated with satellite positioning. However, there is also reason to suggest that some standardization of professional observing and computing procedures should be developed to ensure compatibility and repeatability of results over extended periods of time and regardless of the brand of receiver or post-processing software used.

As an end piece, it is suggested that there is a need for some realignment of surveyors' attitudes. Geodetic development of three-dimensional surveying concepts has been going on for some time, noting inter alia that satellite positioning systems provide three-dimensional results. Nevertheless, surveyors classically tend to think of two-dimensional horizontal position, treating height separately. At the same time, surveyors generally tend to think that the position of a survey monument should be uniquely defined by a single set of unambiguous coordinates. Again, it is suggested that, as satellite systems necessarily relate to world-wide datums, surveyors must become accustomed to the idea that a surveyed monument will in future have a number of sets of coordinates depending upon their means of measurement and their eventual intended use.

REFERENCES

- [1] WEIGHTMAN, J.A. (1983) : Private communication.
- [2] ORDNANCE SURVEY (1981) : Report of an investigation into the use of Doppler Satellite Positioning to provide coordinates on the European Datum 1950 in the area of the North Sea. Professional paper (new series) No. 30.
- [3] Proceedings of the 1st International Geodetic Symposium on Satellite Doppler Positioning, Las Cruces, New Mexico, USA, 1976.
- [4] Proceedings of the 2nd International Geodetic Symposium on Satellite Doppler Positioning, Austin, Texas, USA, 1978.
- [5] Proceedings of the 3rd International Geodetic Symposium on Satellite Doppler Positioning, Las Cruces, New Mexico, USA, 1982.
- [6] ORDNANCE SURVEY, in press. The 1980 readjustment of the triangulation of the United Kingdom and the Republic of Ireland — OS(SN)80. Professional paper (new series) No. 31.