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Terrestrial Methods in Surveying, Mapping and Establishment of Geographic Data Bases

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1991:4 Jonsson B: Kort introduktion till GPS.

1991:7 Becker J-M & Andersson B: Utvärdering av NA 2000 - nytt digitalt avvägningsinstrument. (Engelsk version 1991:15.)

1991:8 Lithén T & Persson C-G: Planering av GPS-nät.

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1992:10 Ekman M: Om lokala massors inverkan på geoiden. (On the Effect of Local Masses on the Geoid - Summary in English.)

1992:14 Hedling G, Jivall L, Jonsson B, Andreasson J: Some Swedish GPS Activities 1991 - Geodetic Control Surveying, Aerial Photography and a Swedish DGPS Network.

1992:16 Almgren K & Sandvik L H: Alternativa metoder vid framställandet av orienteringskartor.

1992:21 Eurenius B & Norin D: GPS inom förrättningsmätning.

1993:1 Ekman M: Geoiden i Sverige och geoidhöjdssystemet RN 92.

1993:2 Ottoson C: Undersökning av Wild GPS-system 200 - GPS-mottagare samt tillhörande programvara.

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1993:5 Svensson R: Utvärdering av geodetiska nät-utjämningsprogram på PC.

1993:7 Hedling G & Jonsson B: PREF - a test of a Swedish network of reference stations for positioning.

1994:14 Johnson M: Regionalt studium av riksnäten med GPS - en homogenitets- och transformationsstudie.

1994:24 RIX 95 - en utredning om förtätning av de geodetiska riksnäten och anslutning av lokala stomnät.

1994:25 Persson K & Persson C-G: Datafångst för GIS med användning av GPS.

1994:28 Reit, B-G: SWEREF 93 - ett nytt svenskt referens-system.

1995:3 Kurkinen, K: Radiolänkar för överföring av GPS-data.

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Terrestrial Methods in Surveying, Mapping and Establishment of Geographic Data Bases

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Huvudinnehåll

I rapporten redovisas dagsläget vad gäller användningen av terrestra (geodetiska) tekniker och metoder vid mätning, beräkning och uppbyggnad av geografiska databaser. Dessa beskrivs och jämförs, möjliga kombinationer av tekniker och metoder exemplifieras och användbarheten i olika sammanhang diskuteras. Särskilt betonas den geodetiska stommätningens betydelse för att åstadkomma väldefinierade referenssystem för alla typer av geografisk datafångst.

Ansatsen är generell men beskrivningen baseras i huvudsak på erfarenheter från Lantmäteriverkets egen forsknings-, utvecklings- och produktionsverksamhet, varför det finns en viss fokusering på svenska förhållanden. Rapporten är ett s.k. "invited paper" till symposiet "Cambridge Conference for National Mapping Organisations", 25 juli - 1 augusti 1995.

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Terrestrial Methods in Surveying, Mapping and Establishment of Geographic Data Bases

Invited paper, Cambridge Conference for National Mapping Organisations,
St John's College, 25 July - 1 August 1995

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Abstract

Terrestrial (geodetic) techniques for surveying, mapping and establishment of geographic data bases include conventional methods – with theodolites, EDM instruments, total stations and levelling instruments as primary tools – as well as GPS and inertial techniques. As in most other disciplines today the modern geodetic methods are to a great extent digitally oriented.

These techniques and methods are briefly described and compared. Their applicability in different situations is evaluated, and examples of possible combinations of terrestrial techniques are given.

The role of, and techniques for, geodetic control surveying – as a tool for establishing reference systems for all types of data collection – are described, and the acquisition of geographic data for both "small scale" (national/regional) and "large scale" (local) applications is discussed.

The approach is general but the description is mainly based on experiences from research, development and production at the National Land Survey of Sweden, thus focusing somewhat on Swedish conditions.

Trends within Geodesy

Geodesy as a science has always provided important support for e.g. mapping, cadastral activities, civil engineering and – together with astronomy – for navigation. The development within geodesy has successively given rise to new possibilities within the fields it supports, and at the same time the needs of these fields have, to a large extent, governed geodetic research and development.

Astronomy has now, in principle, lost its role in navigation and been replaced by "artificial celestial bodies", satellites. These are also used in geodesy, resulting in even closer ties between geodetic surveying and navigational positioning. In spite of satellite technique's substantial influence on geodetic work today, there are also other new techniques in use, e.g. inertial technique for geodetic/geographic data capture. Furthermore, there are various ways of combining old and new techniques and methods, such as GPS, inertial and conventional techniques.

In addition, traditional surveying as such has developed considerably. Thus, the introduction of integrated digital instruments, together with increased computer support in field work, has resulted in continuous digital production lines – from the measurement in the field to the storage of data in a geographic data base.

Trends within Cartography

Cartography is also digitally oriented nowadays. For several decades map data bases were built up, and plotters were used for producing the output, but now the trend is towards totally digital production lines within map production as well. A similar development exists within *CAD (Computer Aided Design).*

For a long time the goal in computer aided mapping and in CAD was to make the production of maps and drawings more efficient. Today, however, the goal is to directly utilize digital data – in planning, analysis, map use etc.

The same trend is evident in the introduction of *Geographic Information Systems (GIS).* These are based on geographic data bases and contain powerful tools for analysis and presentation of geographic information. However, mapping is only one of several applications to be served by a GIS. Analyses in other ways than via map output are at least as important.

A basic idea in the GIS development has been that the same data should be suitable for use in different contexts. It should, for example, be possible to work in parallel at different scales, and the geographic data bases should have such contents and structure that the demands within different application fields can be supplied simultaneously. The application with the strongest demands – regarding e.g. accuracy and/or up-to-dateness – therefore very much governs the design of a data base and the methods to be used in data capture and updating.

Geodesy in a Modern Cartographic Perspective

Geodetic methods are used in mapping and the establishment of data bases in two principally different ways: on one hand as a tool for establishing reference systems – through control networks – for positioning of geographic objects, on the other hand in connection with the data capture itself.

The strength of traditional geodetic surveying, nowadays, is within local measurements – in this context the same as large scale mapping and establishment of "large scale" (detailed) data bases. Among its advantages may be noted

- the high accuracy, yielding well defined control networks and reference systems as well as high geometrical quality in the data bases
- the closeness to the objects to be positioned, i.e. "close sensing" in contrast to the remote sensing used in photogrammetric and satellite based data capture methods
- the comparatively uncomplicated work, which can be performed with relatively inexpensive equipment, with short notice and with one's own staff.

Geodetic surveying is especially suitable in connection with updating, but is used more and more also in the original data capture. With the introduction of the GPS technique, the geodetic methods have become even more competitive. The possibilities of very accurate measurements remain but, in addition, the range has increased considerably and in many applications time as well as costs have been reduced.

GPS - a Revolution in Surveying

GPS (Global Positioning System) is a satellite-based system for navigation and positioning, developed by the US military defence. It is primarily designed for military purposes but is also available for civil use. The use in itself is free of charge. The system consists of 24 satellites, moving in orbits c. 20 200 km above the Earth's surface with a period of almost 12 hours. The satellites transmit coded signals on two frequencies, *L1* and *L2*. The system is being controlled from an operation centre in Colorado Springs.

The basic principle for positioning with GPS is the measurement of distances between the receiver antenna and the satellites which have known positions. From observations of at least four satellites the difference between the clocks of the GPS receiver and the satellite system can be estimated and the X, Y and Z coordinates of the receiver determined. A number of methods for measurement and computation have been developed to meet the demands from various applications, regarding for example positional accuracy and up-to-dateness.

In *absolute positioning,* only the data transmitted from the satellites are used. This yields a positional accuracy of the order of 50-100 metres. To improve the quality one can resort to *relative positioning,* i.e. simultaneous measurements at two or more stations. Depending on the observational and computational methods a relative positional accuracy can be achieved of a few metres *(code measurement)* down to some centimetres *(carrier measurement).*

The GPS measurements can be performed either with a static receiver *(static positioning)* or with a moving receiver *(kinematic positioning).* Also an intermediate mode exists, *semi-kinematic positioning.* The result is obtained either immediately during the field work, i.e. in *real time,* or through *postprocessing* of the observational data.

The arrival of the GPS technique has caused somewhat of a revolution in navigation and positioning. Towards the turn of the century, a more or less complete breakthrough can be expected for GPS in geodetic surveying.

Permanent Reference Stations for GPS

One way of performing relative GPS measurements is by using *permanent reference stations.* Such a station is located on an accurately determined point. It consists of a permanent GPS receiver carrying out continuous observations, together with equipment for computing corrections for real time measurements and storing of postprocessing data.

The accuracy of the measurements depends on the distance to the reference station. To cover large areas – e.g. a whole country – usually several stations are needed, forming a *reference station network.* In such a network there arises a need for an operation centre, for operation and supervision of the reference stations and storage of collected data. There is also a need for equipment for data communication within the net and data distribution to the users.

The same reference station network can be used in several different applications, e.g. navigation, connection of local control networks and data capture for geographic data bases. This combined utilization makes the necessary, quite heavy investments very efficient.

In Sweden, the National Land Survey (NLS), in co-operation with Onsala Space Observatory and the Swedish broadcasting company Teracom, has established the reference station network *SWEPOS* (Jonsson and Hedling, 1994). It consists of 20 stations and is designed for navigation, mainly on land, as well as geodetic positioning – in real time as well as through postprocessing.

The SWEPOS network has been determined in the national coordinate and height systems as well as in the new reference system *SWEREF 93* (Reit, 1994). The latter can be looked upon as the Swedish realization of *WGS 84 (World Geodetic System 1984)*, it becoming thereby possible to utilize GPS rationally and at the same time maintain a link to the traditional geodetic systems.

Data Capture for GIS using GPS

GPS can be used in several ways for data capture for GIS (Persson and Persson, 1994) and mapping. Usually relative GPS measurements are required, e.g. using permanent reference stations, but different measuring principles (code measurement, carrier measurement etc.) may be applied depending on the accuracy required.

In a somewhat simplified manner, however, one can look upon GPS as a "black box" which produces coordinates more or less accurately, in real time or after postprocessing. This "box" consists mainly of a GPS receiver with an antenna, field computer for data storage and computation, a battery and (possibly) radio or telephone equipment for receiving corrections from the reference stations.

GPS can be utilized separately or as support for positioning in other data capture systems or sensors. The technique can be used in creating the geometry in all kinds of geographic data bases, whether they contain information about topography, geology, vegetation or anything else. Since a field computer is supposed to be included in the equipment, there are also possibilities for a simultaneous collection of digital attribute data.

Among the advantages with the GPS technique we have already mentioned high accuracy, wide range, options for real time measurement (i.e. prompt handling of data) and closeness to the objects to be measured. In addition, a common reference station network implies a common reference system and, therefore, order in the handling of coordinates which is also an important quality parameter.

Of course this new technique still has some teething problems, although the rapid development here speaks in favour of GPS soon becoming an every-day-technique. Among remaining problems worth mentioning are:

- The measurement is simple but the computation requires deeper insights, into GPS as well as e.g. coordinate systems. The computer programs, however, are steadily becoming more user-friendly.
- Generally speaking, there is a shortage of GPS competence today (at least in Sweden). Since GPS is now becoming a standard part of surveying education this shortage should be eliminated in the long run.
- Very accurate GPS measurements still take quite a long time, at least over long distances, but the development of measuring methods and computational algorithms are gradually yielding shorter measuring times.

- Free sight towards the satellites is necessary, creating some problems in e.g. towns and cities. On the other hand, GPS is primarily a technique for sparsely populated areas. In urban areas there are normally good control networks to start from, and conventional techniques are, therefore, often more suitable. The penetration of the satellite signals through the forest canopy has been better than expected.
- GPS receivers (for relative positioning) are still quite expensive, but the price difference between such an instrument and a total station is not that substantial.
- The compatibility between receivers or programs from different manufacturers is still not very good. One can, however, notice an increased ambition towards standardization.

What then, can be said about the vulnerability in such a concentration on one single technique and one single satellite system?

First of all, one should note that there is a long time perspective in the engagement of the USA. From their radio navigation plan of 1992 it is clear that the present principles for civil use, e.g. free access to the GPS system, is valid to at least 2003. Moreover, possible policy changes are to be declared at least six years in advance. In any case, we will be able to benefit a lot from the system during that time, at least break-even in our economic ventures. Furthermore, there are advanced plans, e.g. in Europe, to establish a compensating satellite system in case the USA does deteriorate the conditions for the users.

Therefore the future looks bright. New GPS applications mature successively. In this field, the kinematic methods are the most interesting ones. Thus far, GPS has been most suited for data capture for "small scale" (national/regional) GIS; in Sweden the forest applications have attracted most attention, since in this case there are no realistic conventional alternatives to GPS. Today, however, we can perceive a productional use of GPS also in more local applications, e.g. establishing "large scale" data bases with a high accuracy.

Establishment of Horizontal Control Networks

Up to now, establishment of horizontal control networks is the most important surveying application of GPS in Sweden. In NLS, most of the horizontal control surveying is carried out using the GPS technique, since it is at least as accurate as control surveying with conventional techniques, but much cheaper. On average, the price per control point on the Swedish market has been more than halved.

The economic conditions are probably the same for other similar organizations, where the business has such a volume that one can invest in a large number of GPS receivers, thereby making the work more efficient, and still pay the costs. The supply of competence has not been a great problem; the transition from conventional techniques to the GPS technique has been relatively uncomplicated. Nevertheless, education is needed, not only in GPS but also in e.g. handling of computers and computer programs.

Hitherto the control networks have been utilized by traditional surveying. However, the importance of horizontal control networks will most likely change, as will probably their design, if also the utilization of them will be made by GPS in the future.

For certain applications, the purpose of control networks can be expected to be taken over by reference station networks that allow accurate positioning in well determined reference systems and in real time. Nevertheless, horizontal control networks of a traditional kind will be needed in the foreseeable future, especially locally. Local surveying with GPS puts less demands on point density, at the same time as the control points have to be well suited for GPS measurements. It is, for example, not necessary to have a clear sight between the points, but on the other hand free sight is needed upwards, towards the satellites.

Establishment of Height Control Networks

The GPS technique today is not particularly suited for height measurements, at least not of a higher order like national networks. In these applications traditional levelling is still a superior method which, however, contains great possibilities for rationalizing.

In Sweden, a motorized technique is applied in the ongoing third high precision levelling. The equipment includes three cars – two "rod cars" and one "instrument car" – which yields a high production rate. The average daily production is about 12 km, single run. The measuring team consists of four people: the two drivers of the rod cars, and one observer and one driver in the instrument car.

The measurement itself takes place from the platform of the instrument car, using a conventional pendulum instrument (Zeiss Jena Ni 002). The maximum allowed sight length is 50 metres. The observer communicates via radio with the driver of the instrument car who registers the observed values digitally. The driver also reports back whether the measurement, after a check by the computer in the instrument car, has passed or has to be repeated. After the registration of observed data there is a completely digital production line – from the field work to the computation of heights.

The accuracy of the measurements easily meet the requirements of high precision levelling. The standard error of a double-run levelling line is below 1 $mm/\sqrt{km}$. The refraction problems are considerably reduced since the sight line is higher above the ground (2,25 metres) than in traditional levelling. Therefore, the levelling rods are lengthened from the normal 3 metres to 3½ metres. Apart from the fact that everybody in the measuring team must have a driving licence (!), the demands for competence are the same as in all other levelling.

Tests have also been made with "motorized trigonometric levelling" using digital total stations. Thereby the sight lengths can be increased as they no longer need to be horizontal, yielding efficiency profits in hilly terrain. Through corresponding measurements a high accuracy is achieved; the standard error here is also below 1 $mm/\sqrt{km}$.

In spite of the high accuracy, there are some disadvantages with this method. The production rate is some 10 % lower, the production cost 20 % higher and the investment cost 70 % higher, compared to motorized levelling (Becker, 1991). Moreover, higher competence of the staff is required.

To obtain a completely unbroken digital production chain, attempts have also been made to perform motorized high precision levelling with the new digital levelling instruments, e.g. Leica Wild NA 2000/3000 (Becker et. al., 1994) and Zeiss DiNi 10. However, this technique is not at present quite suitable for the purposes in question.

The measurements are disturbed too much by sunlight coming directly into the instrument, the dependence on temperature in the corrections for the collimation error is not handled in a satisfactory manner by the software, and too much work is put on the observer since all data recording is made at the instrument. It should be possible to do something about these shortcomings, thereby increasing the usefulness considerably.

Further Development of the Traditional Techniques and Methods

The most important step in the development of traditional surveying was the introduction of EDM instruments (originally an invention by the Swedish geodesist Bergstrand). This was later followed up by the introduction of digital total stations and field computers, the aim being to create a totally digital handling of data to fit with the general development trend.

A digital data flow is especially important in detailed surveying since, in contrast to control surveying, there are so many measurements to take care of that one cannot handle them manually. For the same reason, great hopes are set on the further development of the digital levelling instruments in those cases where height data are of primary interest.

The total stations are now often equipped with a servo to speed up the procedure. This is especially valuable at setting out, but in combination with "autolock" also in detailed surveying, as the instrument steadily follows the prism. If you also add a telemetric link for remote control of the total station then the recording could be moved to "the source", i.e. the prism, and you have got a "one-man-instrument".

General field computers, which can be connected to all types of geodetic instruments, have the advantages of enabling the same hardware and software to be used independently of the manufacture, as well as measuring without instrument (additional control by measuring-tape etc.). The disadvantage is the addition of an external unit; therefore, solutions with recording and computation in the instrument itself have gained ground.

Here it seems as if so-called PCMCIA cards will become the most common medium for transferring measured data. External, powerful field computers with options for interactive graphics, e.g. pen computers, might become more usual. The advantage in that case is that one can not only record and compute but also work with the graphics in a simple way in the field.

Regarding methods, the application of "free positioning", implying positioning of a freely placed instrument in immediate connection with detailed surveying or setting out, has produced rationalization effects as well as improved quality in the positioning. This method is especially efficient in combination with wall-marked control networks (Persson, 1986), i.e. geodetic networks in which the points are marked on buildings, mainly in urban areas.

Free positioning presupposes, in principle, trigonometric determination of heights. In spite of the above mentioned somewhat discouraging experiences in connection with high precision levelling, such height determination is very useful in local applications. Altogether, the combination of total stations, field computers, free positioning, trigonometric height determination and wall-marked networks is most efficient in urban surveying.

Probably a "motorization", analogous to motorized levelling and motorized trigonometric levelling, would yield additional rationalization effects.

The strength of conventional surveying is, as mentioned earlier, evident in connection with establishment of "large scale" data bases. The geodetic methods become especially interesting in those cases where high accuracy is required and/or where the areas are so limited that the initial cost for aerial photography would be unreasonable. Even when the objects are too small (e.g. boundary points) or blocked (e.g. underground cables), and thus require signalling, it is profitable to use terrestrial methods. The possibilities for simultaneous collection of attribute data yield further advantages.

Integration of Techniques and Methods

Already the fact that GPS and traditional surveying have differing needs for sight – vertical and horizontal, respectively – indicates that the two techniques should complement each other and together create a more optimal solution. For example, GPS could be used separately, conditions allowing, and also for determination of points for measurement with a total station where conventional techniques are more suitable.

There are already examples today of total stations with a GPS antenna added (e.g. Zeiss-Ashtech), where the instrument is positioned by GPS. This, however, requires at least one more GPS positioning for the orientation. An obvious alternative is to equip the total station with a gyro for this purpose, but a more reasonable procedure should be to utilize the principle of "free positioning". This means setting up the instrument on a suitable spot and determining the station by measurements towards a couple of surrounding points which, in the meantime, are positioned by GPS.

This speaks in favour of the GPS antenna being placed with the prism, rather than on the instrument. This should work particularly well when using "one-man-instruments" where the measurement is controlled remotely from the prism anyway.

Positioning by inertial technique has been used to some extent as a data capture method in establishing geographic data bases. The technique requires large investments but is advantageous in special situations (large projects, long objects etc.). NLS owns one such equipment; it has been used for, among other things, measuring optic fiber cables for Swedish Telecom and updating the road network in the national data bases of the Land Survey.

The inertial equipment is placed in a large van; hence the objects to be positioned should be located close to roads. A total station is, however, included as a complement, making excentric measurements possible within a limited distance from the car. Starting from a known point, position differences in three dimensions can be determined with the gyros and accelerometers installed in the system. Because of an unavoidable drift in this kind of system, the inertial platform now and then has to be "calibrated" by additional measurements on known points along the road.

The measurements can be performed with a positional accuracy on the decimetre level – return measurements presupposed – and with a comparatively high production rate. If one is satisfied with a lower accuracy and does not need any benchmarks (such as in the determination of roads for "small scale" data bases), the measurement can, in principle, be made within the speed limit!

A combined utilization of GPS and inertial techniques provides great possibilities for diminishing the need of the inertial technique for continuous access to known points during the data capture. These points can be determined successively by GPS, thereby also eliminating the need for return measurements. Inversely, the problem with signal interruptions caused by blocked sight to the satellites is reduced through relying entirely on the inertial system during those periods. Development within this field is going on at NLS (Lidberg, 1992).

NLS has also used GPS in connection with aerial photography for some years (Jonsson and Norin, 1994). Although this is not a terrestrial application there are reasons to mention the subject since the method may indirectly reduce the need for measurements on the ground.

There are three main stages of aerial photography in which GPS can be used: navigation of the aircraft along the flight lines, triggering of the camera in preselected positions, and accurate (relative) determination of the aerial camera at the time of exposure. The first two stages are well tested. Since the established plan for the photography mission can be followed very closely, the continued photogrammetric process is facilitated.

The third stage is now being investigated. The aim is to be able to use the projection centre of the camera, preferably also GPS measurements of the attitude angles of the aircraft, as additional information in block triangulation, thereby reducing the need for ground control. The investigations have produced promising results that have already been put into practice. The method should be useful in most applications, but for the moment it is used mainly at high flying altitudes.

The possibility of measuring photogrammetric ground control points with GPS should also be mentioned here. This method becomes particularly efficient if permanent reference stations are used, as only one person is required to build the photo signal and perform the GPS measurement. The experiences in connection with signalling for the small scale mapping of NLS are very good. The greatest rationalization effect is in the fact that the ground points can be placed optimally for the photogrammetric measurements.

Conclusions and Future Visions

As is clear from the above, geodetic activities today are very much dominated by GPS; this technique will probably be even more influential in the near future. However, the abbreviation does not stand for "General Problem Solver", traditional methods and techniques will still be important.

The tendency towards completely digital data handling and increased automatization is evident, as is the trend towards the integration of techniques, methods and instruments. This is also combined with a simultaneous treatment of horizontal and vertical data (i.e. a shift to a more three-dimensional way of thinking), an increased contribution of real time applications, and remote control of geodetic instruments.

Thereby, the technical and methodical complexity increases at the same time as the handling of instruments becomes (apparently?) more simple. Because of this, people with quite different qualifications will be required in the future – advanced technicians as well as personnel for the more routine work.

The number of people in the measuring teams is steadily decreasing. Here the new political ambitions to reduce the costs, not the least in public services, are made possible by the new technical achievements. There must, however, be a limit and hopefully we will not see too many "zero-man-instruments", i.e. remotely controlled, pre-programmed, completely automated and perhaps motorized instruments that do not require any human interaction.

Something that should never be forgotten – no matter how digital, streamlined and automatic the new technique appears – is the remaining need for control of both instruments and measurements. The old well-tried geodetic principles in this respect are still valid; we should not become slaves to the technique.

The most important task for the geodesists in the future is probably not a continued development of their own technique, but a transfer of their knowledge to other fields. Geodetic competence is in much demand nowadays and we have a lot to gain by assisting others. Those who believe the GPS development will imply that things such as knowledge in advanced geodesy, experience from surveying, and insight into the problems of coordinate systems are no longer needed are wrong – this is just the beginning!

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