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Reports in Geodesy and Geographical Information Systems

Papers related to SWEPOS
- the Swedish network of permanent reference stations for GPS
Part 1

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NATIONAL LAND SURVEY

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Preface

SWEPOS is the Swedish network of permanent reference stations for GPS and has been in operation since 1993

In this professional paper we have put together SWEPOS related papers which were presented during 1996 and 1997.

The following papers are included:

Hedling Gunnar and Jonsson Bo: New Developments in the SWEPOS Network, The Satellite Division of The Institute of Navigation 9th International Technical Meeting, September 1996, Kansas City, US

Ottoson Christina and Jonsson Bo: Experiences of GPS with cm-Level Accuracy in Real Time, NORNA 96, the 4th Nordic Radio Navigation Conference, in Reykjavik, Iceland, 12 - 15 November 1996

Jivall Lotti and Jonsson Bo: SWEPOS- an Alternative to National and Local Control Networks, the FIG conference in Copenhagen, Denmark, June 2-5, 1997

Abstracts

1. New Developments in the SWEPOS Network

A network of GPS reference stations covering Sweden has been under development since 1991. Currently 21 stations are operating. Twelve of these are also acting as real-time DGPS reference stations. The purpose of the network is to:

- provide single- and dual-frequency data for relative GPS measurements.
- provide DGPS corrections for broadcasting to real-time users.
- provide data for geophysical research.
- act as high precision control points for Swedish GPS users.
- monitor the integrity of the GPS system.

During 1996 the network will be updated to real time capacity using leased lines and the TCP/IP protocol. Raw measurements and DGPS and RTK corrections will be transferred directly to a control centre, where the data will be quality checked, archived and from where the stations are controlled. Data for post-processing can be fetched from the control centre via a BBS or a WWW-server. Distributors of real time DGPS and RTK can get SWEPOS real time corrections from the control centre by a TCP/IP connection.

As a test, integrity monitoring of DGPS corrections will be done at the control centre using data from the SWEPOS station that lies closest to the source station of the DGPS corrections.

Experiments with the transmission of real time kinematic corrections (RTK) from the SWEPOS stations will also be done. First using a GSM cellular phone and later using the DARC FM Sub-Carrier data channel.

This paper contains discussions and experiences from the implementation of the new SWEPOS network.

2. Experiences of GPS with cm-Level Accuracy in Real Time

The first test with carrier phase measurements in real time at the National Land Survey of Sweden (NLS) was done in early 1995. Several test measurements have been made throughout 1995 and 1996 including an investigation of different GPS receivers with these possibilities. The very first dual frequency instruments for this measuring technique were introduced in spring 1994.

Relative carrier phase measurements in real time (also called RTK surveying) have been more and more used during 1996 by the local offices of NLS. The main applications have been measurements of boundary points and details for water supply and sewer systems, especially in the countryside where the benefits of this method compared with traditional methods can be large.

In the near future (within some years) the Swedish network of permanent reference stations for GPS (SWEPOS) will support RTK surveying. Today it is possible to use SWEPOS for carrier phase measurements only in post-processing mode. The problems for real time use today are to find a suitable communication link and handling the difficulties arising from longer distances (> 10 km) to the reference station.

3. SWEPOS- an Alternative to National and Local Control Networks

Permanent reference stations for satellite techniques have advantages over traditional networks. Most of the advantages are due to the fact that the stations are active and the possibility to measure long distances. A requirement for using permanent reference stations as an official multi-user system is that standardised data formats and reference (coordinate) systems are used.

SWEPOS is a network of GPS reference stations covering Sweden, which has been under development since 1991. Currently 21 stations are operating. Twelve of these are also acting as real-time DGPS reference stations. The network is a multi-user system supporting applications from DGPS on m-level to scientific research on mm-level.

SWEPOS has a national coverage for the establishment of local control points on the centimeter level. The conditions are that you are using a high-quality dual-frequency GPS-receiver, at present 24-48 hours observation time and an advanced GPS-processing software. A study is going on in the Ciceron project concerning the possibility of developing a concept, consisting of SWEPOS (maybe densified), improved atmospheric models and a data transmission link, for a real-time service on centimeter level.

Another current study is dealing with the handling of reference networks and reference systems in the future. "How will rational measurements be done in 5-10 years, what reference networks and reference systems are needed to support that and how will we get there" are some of the questions to be discussed in that study.

This paper outlines some ideas how SWEPOS can be used as a basic reference network both on national and local level. Furtheron the SWEPOS network and the Ciceron project are described.

New Developments in the SWEPOS Network

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Abstract

A network of GPS reference stations covering Sweden has been under development since 1991. Currently 21 stations are operating. Twelve of these are also acting as real-time DGPS reference stations. The purpose of the network is to:

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Experiments with the transmission of real time kinematic corrections (RTK) from the SWEPOS stations will also be done. First using a GSM[1] cellular phone and later using the DARC FM Sub-Carrier data channel.

This paper contains discussions and experiences from the implementation of the new SWEPOS network.

Introduction

The Swedish GPS reference station network SWEPOS was outlined during the end of the nineteen eighties and a first draft was published in the paper "Status of a Swedish DGPS network", Hedling&Jonsson (1991).

The current SWEPOS network was designed and built by the National Land Survey together with Onsala Space Observatory. During 1991 and 1992 locations for twenty stations were reconnoitred and six stations became operational. The remaining fourteen stations became operational in the summer 1993. A twenty-first station was located to Borås and became operational in early 1996, see figure 1.

SWEPOS today (September 1996) is operated on a test basis by the National Land Survey. A description of the network is given in Hedling (1995). It is planned that SWEPOS shall be operational in 1997 for real time applications on the

[1] GSM= European standard for cellular communications

Figure 2. Reference station at Skellefteå.

meter level and for post processing applications on the centimetre level. SWEPOS data are already

SWEPOS

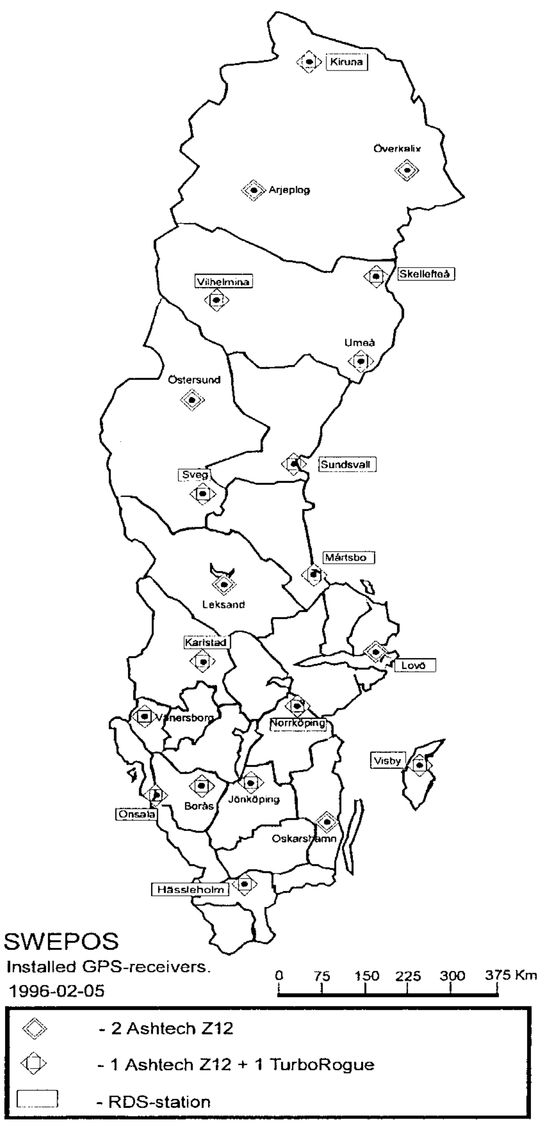

Figure 1. Map of SWEPOS 1996

today usable for a large number of applications, e.g. studies of crustal movements, see BIFROST project (1996) and forestry applications, see Johansson (1994). The goal is that SWEPOS shall be operational for real time positioning on the centimetre level in 1999.

In December 1995 a co-operation group, consisting of representatives from The National Railway Administration, the National Road Administration, the Swedish Civil Aviation Administration, the National Maritime Administration, the Telecommunications Administration, the Swedish State Railways, the Swedish Defence and the Association of Local Authorities, was established. The tasks of the group are to approve the final design of an operational SWEPOS and to contribute to the financing.

User requirements on SWEPOS

Twelve of the SWEPOS stations are used as DGPS reference stations for the EPOS DGPS service, see Hedling (1995) and Sjöberg (1996). EPOS is managed by the Swedish company Teracom, who are also responsible for the broadcasting of the public Swedish Radio and Television channels.

Data for post processing are used for many different objects; photogrammetry, high-precision geodesy, forestry, agriculture, GIS and many avionics and maritime applications. The demands on the data collection rates are varying from geophysics applications who need about 0.01 Hz, to the photogrammetrists who needs 1 Hz and to advanced avionics applications, requiring at least 10 Hz.

Most users of the SWEPOS data want data that is quality controlled and the real time users of course need integrity monitoring.

Currently the main quality checking is done by a post-processing program which operates on Rinex files. Integrity monitoring of the real time data is rudimentary.

These user requirements have led the National Land Survey to develop a WAN (Wide Area Network) communications network for SWEPOS, with near real-time access to all data.

System architecture

All the SWEPOS stations will be connected to a central node or control centre using a TCP/IP over

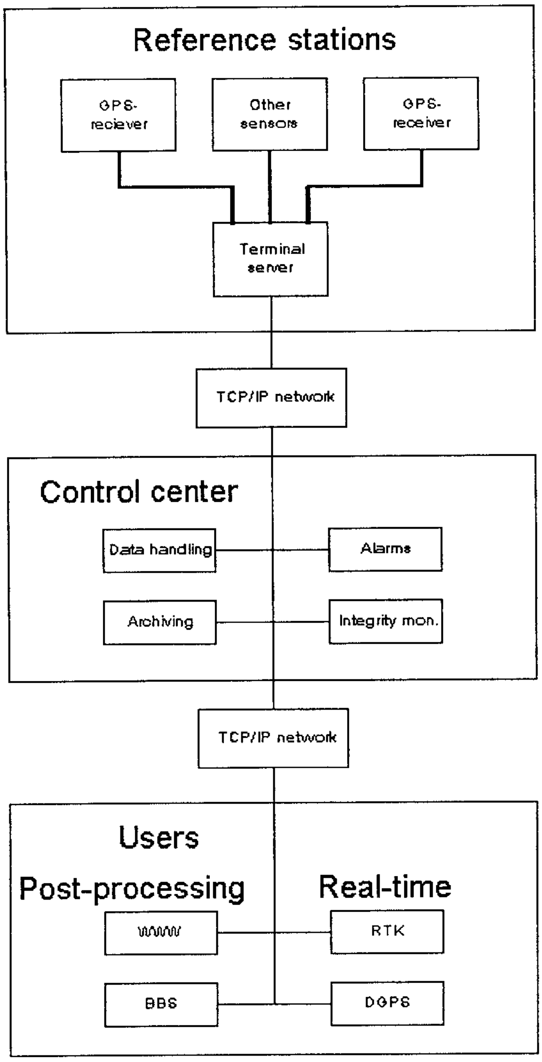

Figure 3 New SWEPOS Design

frame relay communications network. 1 Hz raw observation data and RTCM correction data will be sent by the communications channels. Communication with other types of sensors like meteorology sensors and battery loaders will also use this communications channel. The control centre will have access to all the observations in near real time.

TCP/IP was chosen because it is a standard communications technique today and because it adds extensibility to the network. Frame relay - which is an updated version of the older packet protocol X.25 - was chosen because it brings economy to wide-area networking.

1 Hz data rate was chosen because it is a common denominator for many GPS applications. 2 Hz data rate will be supported optionally.

To compute corrections at the reference stations and then send them to the control centre can be a cumbersome solution, it was chosen because if you instead computes corrections at the control centre, unnecessary latency is added to the corrections.

Integrity monitoring

Integrity monitoring in the SWEPOS network has been lagging behind since the start of the SWEPOS project. Partly because the correction data is sent over large distances to the distribution network i.e. the Swedish FM radio network and partly because this distribution network compromised a powerful monitor for the distribution. At the central node of the FM radio network where all the RTCM correction data pass, correction data from a bad reference station can quickly be replaced by correction data from a neighbouring reference station. All this made a solution with integrity monitors at the reference stations less attractive.

In a first phase SWEPOS will use the available rawdata and DGPS corrections at the control centre to implement a central integrity monitor. This integrity monitor will use rawdata from the nearest "neighbour" to a reference station to monitor DGPS data from the first station. If the monitoring neighbour fails then other neighbours can easily take over the role as integrity monitors.

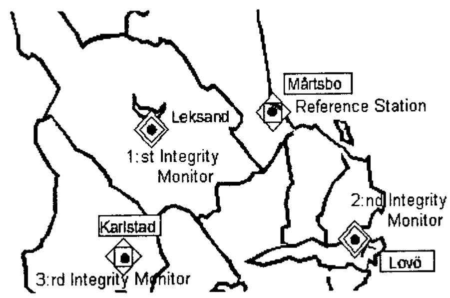

Figure 4 Small map which shows the main and back-up integrity monitors.

This integrity monitor can simply be implemented using the TCP/IP streams with data from the reference stations that are already available at the control centre.

An integrity monitor program developed by Navdata in Finland will be installed during this autumn. This program has the following important features:

- uses the TCP/IP protocol.
- central integrity monitoring.
- standard RTCM/RSIM integrity monitoring.
- automatic switch-over between integrity monitor stations.
- uses the UKOOA Guidelines for DGPS (1994)
- real time kinematic (RTK) integrity monitoring.

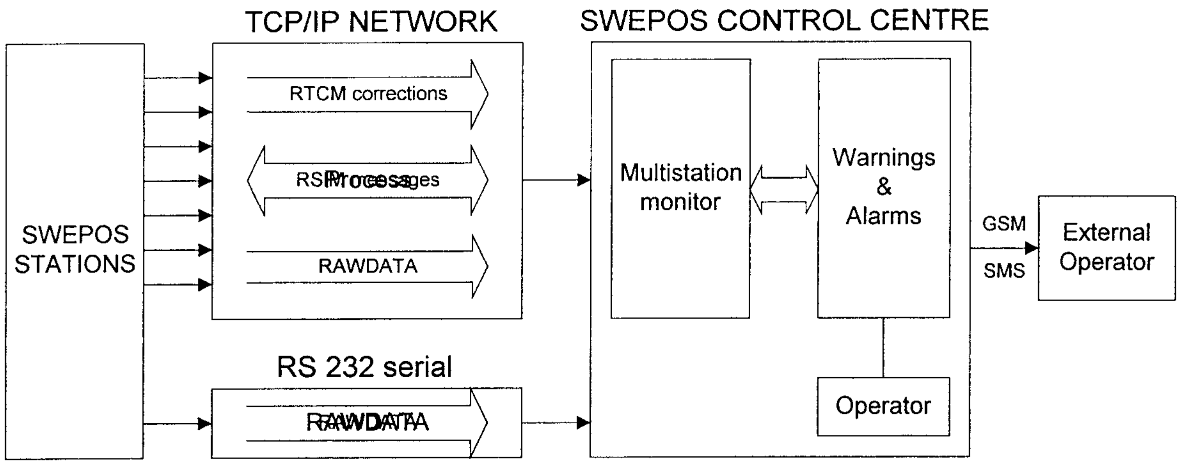

Figure 5 Diagram of the SWEPOS Integrity Monitor

- automatic warning messages sent via the GSM-SMS messaging service[2]

The central integrity monitoring concept has a weak point in the fact that it is dependent on a single communications link to the reference stations. To improve the redundancy the National Land Survey plans to install additional communication links to the SWEPOS stations in the future. The most likely candidate for this link is the 64 kbps cellular (GSM) communications channel that is just becoming available in Sweden.

Special problems

Heating

The SWEPOS cabins have a thick isolation, this was to protect the equipment from the cold which was seen as a major problem at the start of the project. With the increasing number of electronic instruments, that have been placed in the cabins: GPS receivers, PC's, atomic oscillators, batteries, battery loaders etc, the problem has become the reverse: Too much heat. Since we foresee even more equipment in the cabins in the future: meteorological sensors, network equipment and Glonass receivers, the National Land Survey have installed air-conditioning in all stations.

Radomes

The SWEPOS monuments are described in Hedling (1995). Because of the abundant snowfall especially in northern Sweden, the choke-ring antennas (TurboRogue type) are covered by radomes. These have proved to be a special problem area because they tend to influence the phase centre of the antenna. This influence is significant in high-precision applications and when the user use other types of GPS antennas together with SWEPOS observations.

In 1993 small conical fibre-glass radomes where installed on all stations (see figure 2). These proved to be quite good except in the winter when much snow and ice did cling to the top of the pillars, around the radome. This sometimes affected the height estimates by as much as a couple of centimetres, see Jaldehag (1995).

Figure 6 Large conical radome in Vilhelmina

In 1994 larger conical radomes made from fibre-glass and gelcoat where installed on all the stations except Onsala. With these, the snow and ice problems disappeared but instead some of these radomes induced very strong phase centre variations.

People at Onsala and at the National Land Survey is therefore working with new types of radomes. One possibility would be to use Gore-tex fibre, another interesting material is Plexiglas, which among other things has a lower permittivity constant than fibre-glass. Two models are investigated: conical and hemispherical, of which the hemispherical currently seems to be slightly better, this model, on the other hand can be

[2] GSM-SMS=messaging subsystem of GSM

problematic during snowy winters. Paint with non-metallic pigment is also investigated.

In figure 7 the relative height estimates is plotted against the elevation cut-off for a four station sub-network of SWEPOS. Onsala has an older type of

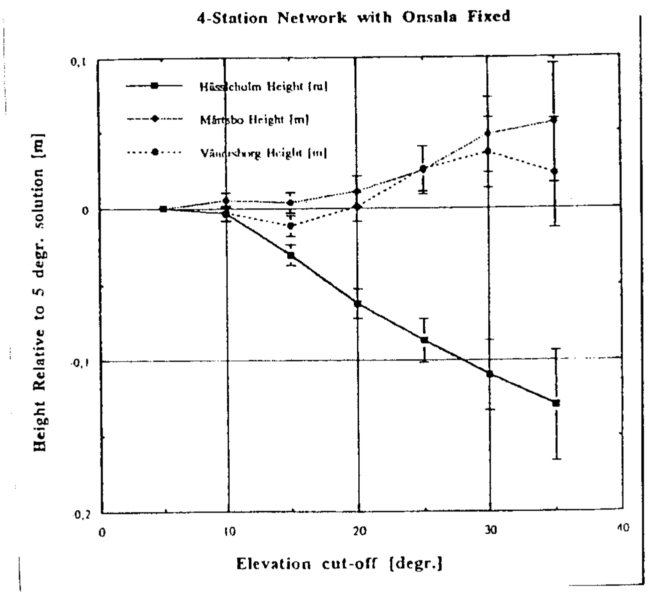

Figure 7 Height difference plotted versus elevation cut-off for 3 baselines in SWEPOS (from J. Johansson, personal communication).

fibre-glass radome, Hässleholm has a big fibre-glass and gelcoat radome, Vänersborg and Mårtsbo have hemispherical Plexiglas radomes. In the diagram it can be seen that the height estimate of Hässleholm is clearly correlated with the elevation cut-off. Ideally there should be no correlation and the diagram indicates that the stations with hemi-spherical Plexiglas radomes comes closer to no dependency upon elevation cut-off.

Real time kinematic surveying in SWEPOS

Real-time kinematic surveying with SWEPOS data is a field where we so far have no practical experience. SWEPOS data in post-processing mode have been used for several years to position the camera centre in photogrammetric surveying. The computations are done after the survey. The computations use the ionosphere-free carrier phase observable and no ambiguity resolution is tried. RTK surveying using proprietary protocols and low-power radio links at distances < 15 km from a temporary reference station has been used extensively at the National Land Survey during the last two years.

The results are so encouraging that a service for sending RTCM/RTK corrections from SWEPOS is planned.

To optimise a RTCM/RTK service, Onsala Space Observatory, National Land Survey and Teracom have decided to co-operate in a project that shall pinpoint and possibly solve problems for such a service. This project shall also do research in related areas and develop algorithms that shall make it possible for the service to provide an accuracy of better than 1 dm 95% of the time at distances up to 100 km from a reference station.

In this project we will use a communications channel called DARC (Data Radio Channel). DARC is a new FM sub-carrier data channel of the same type as RDS (Radio Data System) or RBDS (Radio Broadcast Data System) in USA. DARC is also a standard approved by ITU (International Telecommunication Union).

The main difference between these systems is that DARC has a much higher data rate, 16000 bps raw rate compared with the 1100 bps of RDS. Important technical issues that needs to be solved before a successful service can be started are:

- ambiguity resolution.
- tropospheric corrections.
- ionospheric corrections.
- multiple reference stations or not ?
- GPS with or without GLONASS ?
- Is a denser network of reference stations necessary ?
- transmission protocols in DARC.

Finally, the projected start of the RTK service in 1999 will incidentally be one year before the next sunspot maximum with severe ionospheric disturbances in the high latitudes. This makes the project interesting indeed.

Conclusions

The SWEPOS network of reference stations for GPS has been under development for 5 years now. A real-time DPS service - the EPOS service managed by Teracom - using SWEPOS data have been operational for almost 2 years. Data from SWEPOS is routinely used in post-processing mode for among other things photogrammetric surveying. Studies of the Fennoscandian land uplift and the atmosphere are pursued at Onsala Space Observatory using SWEPOS data. In 1997 the SWEPOS will be declared operational for post-processing and DGPS use.

The National Land Survey, Onsala Space Observatory and Teracom are just about to start (autumn 1996) a project whose goal is to develop a real-time kinematic service based on the DARC communications channel. It is planned that this service will be operational in 1999 and that it will be able to provide centimetre- level accuracy's in real-time over the greater part of Sweden.

In December 1995 a co-operation group with representatives from several government administrations in the communications, transportation and defence spheres was formed. This group shall approve the final designs of the operational SWEPOS. The time when SWEPOS is planned to be fully operational is set to1999. This co-operation group is also contributing to the financing of the SWEPOS development.

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Experiences of GPS with cm-Level Accuracy in Real Time

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Abstract

The first test with carrier phase measurements in real time at the National Land Survey of Sweden (NLS) was done in early 1995. Several test measurements have been made throughout 1995 and 1996 including an investigation of different GPS receivers with these possibilities. The very first dual frequency instruments for this measuring technique were introduced in spring 1994.

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In the near future (within some years) the Swedish network of permanent reference stations for GPS (SWEPOS) will support RTK surveying. Today it is possible to use SWEPOS for carrier phase measurements only in post-processing mode. The problems for real time use today are to find a suitable communication link and handling the difficulties arising from longer distances (> 10 km) to the reference station.

Introduction

The GPS activity at NLS started already in 1985. In collaboration with other GPS users in Sweden a test network for GPS measurements was established. During the time period 1987 to 1990 pilot projects were carried out in different types of GPS applications.

The launch of the first GPS Block II satellite in February 1989 and the arrival of a new generation of GPS receivers made it possible to use GPS routinely for geodetic measurements, e.g. densification of the national triangulation network and establishment of control networks.

Aerial photography is one of the major activities at the NLS. In order to get an impression of the capability of GPS in this field of applications, experiments were carried out in 1989, 1990 and 1992. In the aerial photography for the Kuwait-Iraq border demarcation in 1991, GPS was used for navigation and automatic exposures at preselected positions. Since 1992 GPS is routinely used in these applications. In addition, post processed GPS data are used to position the camera centre at the time of the exposure. This reduces the number of ground control points.

Another major activity in the NLS organisation is surveying of details, e. g. cadastral surveying and data capture for "large scale" GIS (Geographical Information Systems). During 1992 and 1993 NLS has investigated the possibilities to use GPS for cadastral surveying. This led to an implementation of the GPS technique, starting at some local offices in June 1994.

A condition for a breakthrough of GPS for surveying of details is Real time GPS with cm level accuracy.

Kinematic real time carrier phase measurements

Relative carrier phase measurements in the static mode give a high accuracy and reliable result with a standard error of some millimetres, but the observation time varies from some minutes to hours or days depending on the baseline length and the conditions for the GPS observations. This method is used mainly for the establishment of control networks.

For many applications the accuracy requirements are on the centimetre level (or lower) with an observation time as short as possible, i. e. some seconds to some minutes. Relative carrier phase measurements in the kinematic mode are used for these purposes. The results can be obtained by post-processing or in real time.

One GPS receiver is placed on a point with a known position (a reference station) and one or more receivers (the rovers) are moved to objects or along paths which shall be positioned. In order to achieve cm accuracy it is necessary to resolve the integer cycle ambiguities of the carrier phase by an initialisation procedure before the actual position determination can start. The initialisation can be performed by observing with the rover on a known point or during the transport between the stations using the "on the fly ambiguity resolution technique". The last technique requires dual frequency receivers.

In the semi-kinematic mode the rover is placed statically over the point to be positioned for a short time period, while the rover is moving continuously in the kinematic mode. The reliability is higher in the semi-kinematic mode than in the kinematic mode. To resolve the integer cycle ambiguities of the carrier phase at least five satellites are needed. After the initialisation procedure is made and as long as four common satellites are observed at the reference station and by the rover the determination of the positions can be done instantaneously. As soon as less than four satellites are observed a reinitialisation must be made.

For high productivity in positioning and for high precision navigation it is necessary to obtain the results from the GPS observations in real time, the method is called "Real Time Kinematic carrier phase measurement" or RTK surveying.

To do relative carrier phase measurements in real time a communication link is necessary for the transmission of data from the reference receiver to the rovers. Real time implies that the computations of the positions generally are performed directly inside the mobile receivers (the rovers).

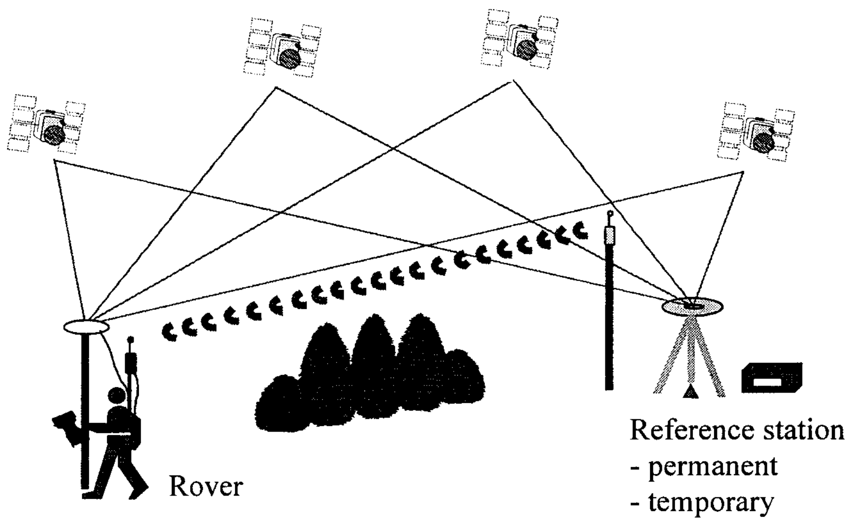

Figure 1. *Relative carrier phase measurements in real time.*

The relatively large amount of transmitted data requires a transmission rate in the order of 2400 - 9600 bps. In the Nordic countries you are only allowed to transmit data with a maximum power of 1,0 Watt in the frequency range 439.700 - 439.975 MHz without a licence. Unfortunately this power is only sufficient for about 2 - 5 km on land, depending on a lot of circumstances, e.g. the topography, buildings and vegetation. To transmit at a higher power than 1,0 W you need a licence from the Board of Telecommunications.

Today the manufacturers of RTK systems use proprietary formats for the data transmission between the reference station and the rover. The recommended standard format RTCM ver 2.2 is not yet fixed (Oct. 1996). In the long run the manufacturers have to meet the strong user requirements of a common standard format for the data transmission between the reference station and the rover.

The very first instruments with the possibility for dual frequency carrier phase measurements in real time were introduced in 1994. Nowadays (Oct. 1996) this technique is well known and there are at least five manufacturers of such instruments.

Initial tests of RTK surveying

Today the main part of the RTK surveyings in Sweden, apart from the RTK system for the Öresund link, are based on temporary reference stations which are established for a specific survey at control network points. The baseline lengths are usually less than 15 km.

Already in 1989 NLS tested the concept of semi-kinematic carrier phase measurements for detailed surveying, [4] and kinematic carrier phase measurements for the determination of the position of the aerial camera at the moment of the exposure in aerial photography, [7]. At that time the initialisation procedure was made using observations with the rover on known points. The computations were carried out after the measurements.

The very first test with carrier phase measurements in real time at NLS was carried out in April 1994. At that time the computation of the positions were performed in a lap top and the data were transferred from the local reference station to the rover via a cable.

The first test with carrier phase measurements in real time at NLS using a radio link for the data transmission was done in early 1995 at the test field in Rörberg. It was shown that it is possible to reach cm accuracy with the RTK concept, [10]. During spring 1995 routines for field measurements with our RTK system were developed. More test measurements and training of surveyors were made during the field season 1995 with the aim of finding a useful system for the applications, measurements of boundary points and details for water supply and sewer systems.

In September 1995 the Ashtech , Leica and Trimble RTK systems were tested at the test field of the NLS observatory Mårtsbo outside Gävle, [11]. The three systems were tested along the same trajectory at the test field in the same satellite window on subsequent days. Real time results were compared with post-processed results. The main aim was to study the performance of the systems. The design of the Leica system is a little bit different from the Ashtech and Trimble systems, but we found a very similar performance of the three systems. The Geotronics RTK system was available in February 1996 for a test. We found that the performance of the Geotronics system agrees very well with that of the other systems, which were tested in September 1995.

RTK surveying in the future

During the autumn 1995 NLS carried out RTK test measurements in urban environments, [3], and the National Rail Administration in railway environments, [2]. The two projects indicated that the RTK measurements did not give the same accuracy as measurements with a total station. These indications led to an investigation of the capability of the RTK surveying. In a first step different antenna types for RTK surveying were investigated, since the GPS antenna is an important part of a RTK system when looking for high accuracy.

The test measurements were carried out at the test field in Rörberg during the summer 1996. The investigated antennas were Ashtech Dorne-Margolin (with choke ring, 4.1 kg), Ashtech Precision (with ground plane, 1.7 kg) and Ashtech Mariner III (1.1 kg). Ashtech receivers were used.

No significant accuracy differences could be found horizontally. On the other hand the differences in height were larger. Also the time to solve the integer ambiguities varied; on the average 19 sec. for Ashtech Dorne-Margolin, 33 sec. for the Ashtech Precision and 37 sec. for the Ashtech Mariner III. In conclusion the Dorne-Margolin antenna gave the fastest and most accurate result but this antenna is also the heaviest and largest one, see figure 2.

It is always a balancing between the most accurate devices and the most practical ones. The equipment which gives the highest accuracy and reliability is often a little bit bulkier and more expensive. The practical part can be especially important when carrying the equipment on your back.

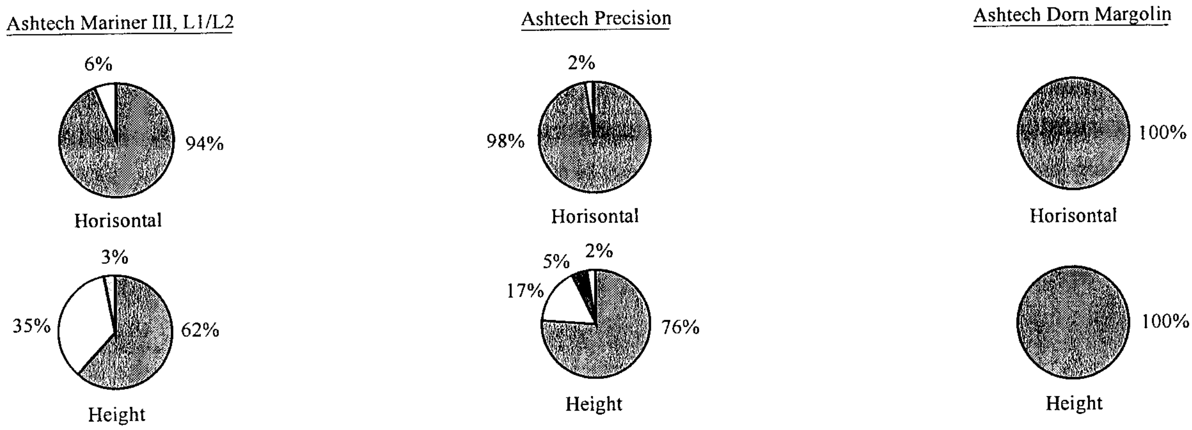

Figure 2. *Difference between known and measured values.*

▩ *difference < 1 cm*

☐ *1 cm < difference < 2 cm*

■ *2 cm < difference <3 cm*

☐ *3 cm < difference <4 cm*

As a Master of Science thesis (carried out at NLS) RTK surveying was investigated under poor satellite visibilities [9]. The tests were carried out in different types of forests, with respect to the density and kind of trees. The test areas were chosen to be similar to the situation in cadastral surveying. Equipment from Ashtech were used in the tests.

The investigation showed that unstable solutions can give rise to incorrect results, even if the carrier phase integer cycle ambiguities are resolved. If the integer cycle ambiguities are not resolved the internal quality value is much more unreliable.

Because of the development of the RTK surveying, GPS has become of interest for local surveys. When using GPS the distances between the points can be increased because no line of sight is needed. A closely related question is how our local control networks should be maintained and be built up in the future. Some questions related to this have been studied in a project at NLS, [3].

Even if GPS is excellent on many occasions, GPS can never be used everywhere. Therefore it is important to find possibilities to combine GPS with other methods. During the winter 1997 NLS will study how to combine GPS and a total station in the best way. Probably there are also other interesting techniques, e.g. laser instruments.

Applications of RTK surveying

Carrier phase measurement in real time has been more and more used during 1996 within the whole organisation of NLS, which is spread all over the country. Today there are ten RTK surveying equipments in use at NLS. The main applications have been measuring of boundary points and details for water supply and sewer systems.

Other applications are e.g. measurements of power lines and ski-tracks for the next years Swedish skiing championship. During the measurements of the ski-tracks the instruments were placed on a snow-mobile. Because of the high surrounding vegetation the GPS antenna was mounted on a mast which could be raised quickly for every measurement by an air pump.

The benefits of RTK surveying compared to traditional methods can be large, especially in the countryside. Unfortunately this method is not suitable in the center of cities since there are too many obstacles to the satellites signals there. The obstacles can both make the satellites invisible and give rise to multipath.

SWEPOS - A Swedish Network of Reference Stations for GPS

SWEPOS consists of 21 stations placed at a distance of 200 km from each other. The network has been designed and established by the National Land Survey of Sweden in co-operation with Onsala Space Observatory. During 1991 and 1992 locations for 20 stations were reconnoitred and six stations became operational. The remaining 14 stations became operational in the summer 1993. A 21st station was located at Borås and became operational early 1996. The current status of the SWEPOS network is summarised in [5] and figure 3.

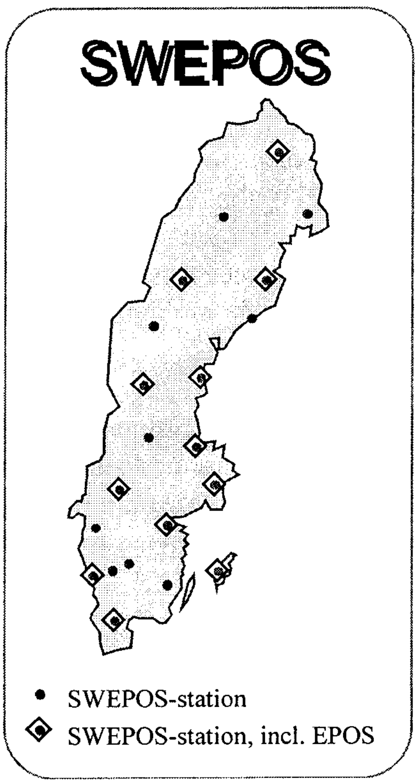

Figure 3: *Map of SWEPOS.*

The purpose of the SWEPOS network is to

- provide single- and dual-frequency data for relative GPS measurements,
- provide differential corrections for broadcasting to real-time users,
- provide data for studies of crustal dynamics, due to the land uplift,
- act as high-precision control points for Swedish GPS users and
- monitor the integrity of the GPS system

SWEPOS is today (October 1996) operated on a test basis by the NLS. The plans are that SWEPOS shall be operational for real time applications on the meter level and for post-processing applications on the centimetre level during 1997, but SWEPOS data are already today usable for a large number of applications, e. g. studies of crustal movements, [1], and forestry applications, [6]. The goal is that SWEPOS shall be operational for real time positioning on the decimetre level or better in 1999 over the major part of Sweden.

Today it is possible to use SWEPOS for carrier phase measurements with post processing. These data are so far available at no cost for Swedish users via Internet or a Bulletin Board Service. It is also possible to use SWEPOS for DGPS (code measurements). The differential corrections from 12 of the stations are broadcast via the RDS channel on the FM-network by the TERACOM Svensk Rundradio company. This service is called EPOS. TERACOM is also responsible for the broadcasting of the public Swedish radio and television channels.

RTK surveying with centimeter level accuracy using SWEPOS

Real time surveying with cm level accuracy using SWEPOS is a field where we so far have no practical experience. The problems in using SWEPOS for carrier phase measurements in real time are to find a suitable communication link and to handle the difficulties arising from longer distances (> 10 km) to the reference station. To optimise a RTCM/RTK service NLS, Onsala Space Observatory and TERACOM have decided to co-operate in a project that hopefully will solve these problems during 1997 - 1998. The goal is to reach an accuracy of better than 1 dm during 95 % of the time at distances up to 100 km from a reference station. In a longer perspective even better accuracies are of course imagined.

The radio link used for broadcasting the differential corrections is RDS (Radio Data Systems). This system is not sufficient for carrier phase measurements since the amount of data is too large. Therefore another radio system has to be used. Up to now a system called DARC (DAta Radio Channel) has been discussed. DARC is a new FM sub-carrier data channel of the same type as RDS. DARC is also a standard approved by ITU (International Telecommunication Union). The main difference between the systems is that DARC has a much higher data rate, 16 000 bps raw rate compared to the 1 100 bps of RDS.

Today it is only possible to measure at a maximum distance of about 10 - 20 km from he reference station to achieve cm - dm accuracy, depending on different conditions of the ionosphere and the troposphere. The goal is to reach a high accuracy even at longer distances, up to 100 km, which is the same as the maximum distances to our reference stations in SWEPOS.

Before a successful service can be started some technical issues needs to be solved:

- ambiguity resolution
- tropospheric corrections
- ionospheric corrections
- multiple reference stations or not?
- GPS with or without GLONASS?
- is a denser network of reference stations necessary?
- transmission protocols in DARC

Conclusions

Today (October 1996) GPS is used routinely in many applications at the National Land Survey and the possibility to provide real time positions on a cm-level will make GPS very efficient for more applications, e. g. high precision navigation and surveying of details.

RTK surveying is used for distances between the reference receiver and the rovers up to 15 km. Points in the existing control networks are used as reference points. Further developments are required to clarify the capability and reliability of RTK surveying; GPS antennas, two reference stations, etc. The National Land Survey has started such an investigation.

To solve the phase ambiguities five satellites are necessary. This brings about that surveying is not possible all over the day, especially when measuring at places where some satellites are not visible. A combination of GPS and GLONASS will improve the possibilities to use RTK surveying.

So far we have very little practical experience of real time surveying using the Swedish network of permanent reference stations, SWEPOS. A co-operation project between Onsala Space Observatory, National Land Survey and Teracom will study the conditions for a RTCM/RTK service during 1997-1998.

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SWEPOS- an Alternative to National and Local Control Networks

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ABSTRACT

Permanent reference stations for satellite techniques have advantages over traditional networks. Most of the advantages are due to the fact that the stations are active and the possibility to measure long distances. A requirement for using permanent reference stations as an official multi-user system is that standardized data formats and reference (coordinate) systems are used.

SWEPOS is a network of GPS reference stations covering Sweden, which has been under development since 1991. Currently 21 stations are operating. Twelve of these are also acting as real-time DGPS reference stations. The network is a multi-user system supporting applications from DGPS on m-level to scientific research on mm-level.

SWEPOS has a national coverage for the establishment of local control points on the centimeter level.The conditions are that you are using a high-quality dual-frequency GPS-receiver, at present 24-48 hours observation time and an advanced GPS-processing software. A study is going on in the Ciceron project concerning the possibility of developing a concept, consisting of SWEPOS (maybe densified), improved atmospheric models and a data transmission link, for a real-time service on centimeter level.

Another current study is dealing with the handling of reference networks and reference systems in the future. "How will rational measurements be done in 5-10 years, what reference networks and reference systems are needed to support that and how will we get there" are some of the questions to be discussed in that study.

This paper outlines some ideas how SWEPOS can be used as a basic reference network both on national and local level. Furtheron the SWEPOS network and the Ciceron project are described.

PERMANENT REFERENCE STATIONS FOR SATELLITE TECHNIQUES AS AN ALTERNATIVE TO TRADITIONAL NETWORKS

Traditional networks

Traditional networks consist of stations with known coordinates which a user visits with his own equipment and makes his measurements from. Due to the technique used when determining the traditional networks, they are separated in horizontal components and height. Distance and angle measurements are used for horizontal networks and levelling for height networks. Furthermore the tradional networks are divided into orders, where each lower order is a densification of the higher one. The traditional measuring techniques do also have a larger scale dependent error than modern satellite based techniques. The quality of tradional networks is marked by high internal accuracy between adjacent stations but lower accuracy over longer distances.

Satellite techniques work three dimensionally and, to fully support that, also the reference networks need to be three dimensional.

Permanent reference stations versus traditional geodetic networks

Permanent reference stations for satellite techniques have advantages over traditional networks. For a user it means:

- time saving by not having to find the station
- time and equipment saving by not having to measure and transmitting data from the station
- greater possibilities to connect the measurements to more stations, which means higher accuracy and reliability
- smaller risk of mixing up stations and coordinates
- no bother about centering errors
- no conflict with other users when trying to use the same station at the same time
- possible movements of reference points are monitored
- measuring technique which implies further reliability.

A disadvantage with permanent reference stations, which also is due to the fact that the stations are active, is that the network is technique dependent. GPS is the technique which today is used for such permanent stations, in the future other satellite based tecniques like GLONASS and GNSS will be used as well. The satellite based technique could not be used everywhere (tunnels are certainly a problem) and some details can't be measured either (house corners).

The satellite techniques have the advantage that they work over long distances with high accuracy, which means that the separation between the stations could be much longer than in conventional control networks. This does however imply problems when the new measurements are combined with existing deformed reference systems originating from traditional networks.

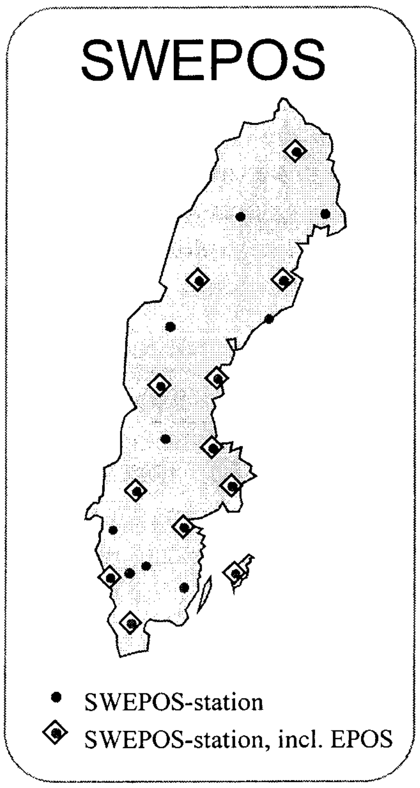
There are good reasons to believe that permanent reference stations for satellite techniques will play a big role in the future. The question is to what extent permanent reference stations will replace traditional control networks.

Permanent reference stations as a national and local control network

A requirement for using permanent reference stations as an official multi-user system is that standardized formats and reference (coordinate) systems are used. This enables all users to utilize the stations, not just the ones who have established them. If a national network of permanent reference stations is going to be used aslo on a local level, there has to be good conditions for using the national reference system locally, e.g. transformation formulas have to exist.

Another question is who is establishing and maintaining the permanent reference stations if more stations are needed on the local level than could be supported by a national network. There is a point in a collaboration with a national network like SWEPOS. The same routines for maintenance and quality control as well as the same data distribution channel could be used for the local stations as for the existing national ones. Advantages with this concept compared to a number of local networks of permanent reference stations is the use of standardized formats and coordinate systems, which make the network open to many users, and the rationalization that the common maintenance implies.

SWEPOS



SWEPOS consists of 21 stations placed at a distance of 200 km from each other. The network has been designed and established by the National Land Survey of Sweden in co-operation with Onsala Space Observatory. During 1991 and 1992 locations for 20 stations
were reconnoitred and six stations became operational. The remaining 14 stations became operational in the summer 1993. A 21st station was located at Borås and became operational early 1996. The current status of the SWEPOS network is summarised in [Hedling, Jonsson 1996].
The purpose of the SWEPOS network is to:

- provide single- and dual-frequency data for relative GPS measurements.
- provide DGPS corrections for broadcasting to real-time users.
- provide data for geophysical research, due to the land uplift.
- act as high precision control points for Swedish GPS users.
- monitor the integrity of the GPS system.

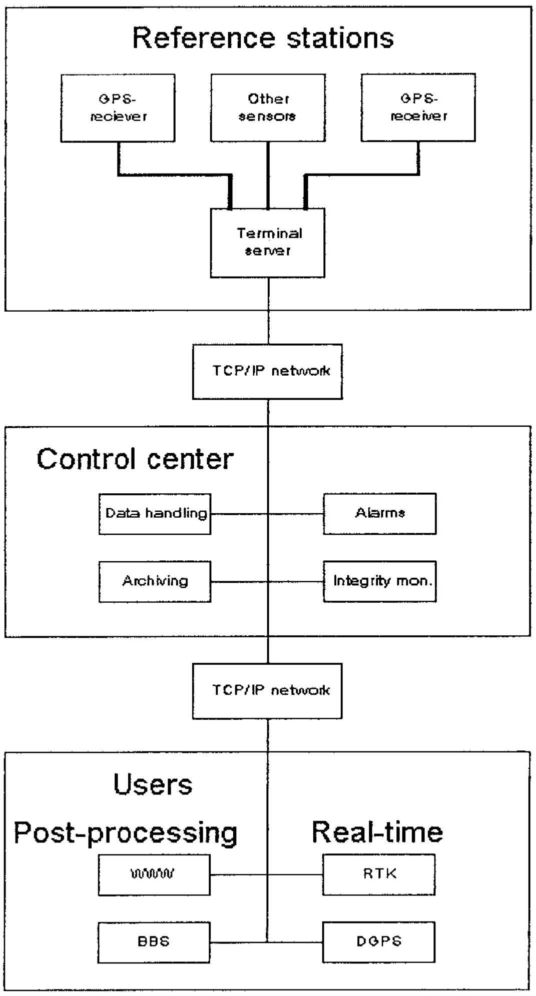
The SWEPOS network defines the high-quality reference system SWEREF 93 which is connected to EUREF 89. The DGPS-corrections as well as the RTK-corrections are provided in the standardized RTCM ver 2.1 format and raw data for post processing in the RINEX (Receiver Independent Exchange) format.

User requirements on SWEPOS

Twelve of the SWEPOS stations are used as DGPS reference stations for the EPOS DGPS service, see Hedling (1995). EPOS is managed by the Swedish company Teracom, who is also responsible for the broadcasting of the public Swedish Radio and Television channels. Data for post processing are used for many different objects; photogrammetry, high-precision geodesy, forestry, agriculture, GIS and many avionics and maritime applications. The demands on the data collection rates are varying from geophysical applications which need about 0.01 Hz, via the photogrammetrists who needs 1 Hz and to advanced avionics applications requiring at least 10 Hz.

Most users of the SWEPOS data want data that is quality controlled and the real time users of course need integrity monitoring. Currently the main quality checking is done by a post-processing program which operates on Rinex files. Integrity monitoring of the real time data will be implemented in June 1997.

These user requirements have led the National Land Survey to develop a WAN (Wide Area Network) communications network for SWEPOS, with near real-time access to all data.



System architecture

All the SWEPOS stations are connected to a central node or control centre using a TCP/IP communications network. 1 Hz raw observation data, DGPS-corrections and RTK-data will be sent by the communication channels. Communication with other types of sensors like meteorology sensors and battery loaders will also use this communication channel. The control centre will have access to all the observations in near real time.

TCP/IP was chosen because it is a standard communication technique today and because it adds extensibility to the network. 1 Hz data rate was chosen because it is a common denominator for many GPS applications. 2 Hz data rate will be supported optionally.

To compute corrections at the reference stations and then send them to the control centre can be a cumbersome solution, it was chosen because if you instead computes corrections at the control centre, unnecessary latency is added.

Real time kinematic surveying in SWEPOS and the project Ciceron

Real-time kinematic surveying with SWEPOS data is a field where we so far have very little practical experience. SWEPOS data in post-processing mode have been used for several years to position the camera centre in photogrammetric surveying. The computations are done after the survey and no ambiguity resolution is tried.

RTK surveying using proprietary protocols and low-power radio links at distances < 15 km from a temporary reference station has been used extensively at the National Land Survey during the last two years.

The results are so encouraging that a development project for the design of a service for sending RTCM/RTK corrections from SWEPOS has started. In the meantime RTK data will be available via GSM celluar phones from all SWEPOS stations.

Ciceron is a co-operation between Onsala Space Observatory, National Land Survey and Teracom and shall pinpoint and possibly solve problems for a RTCM/RTK service. This project shall also perform research in related areas and develop algorithms that shall make it possible for the service to provide an accuracy of better than 1 dm during 95% of the time at distances up to 100 km from a reference station.

In this project we will use a communication channel called DARC (Data Radio Channel). DARC is a new FM sub-carrier data channel of the same type as RDS (Radio Data System) or RBDS (Radio Broadcast Data System) in USA. DARC is also a standard approved by ITU (International Telecommunication Union).The main difference between these systems is that DARC has a much higher data rate, 16000 bps raw rate compared with the 1100 bps of RDS. Important technical issues that need to be solved before a successful service can be started are:

- ambiguity resolution.
- tropospheric corrections.
- ionospheric corrections.
- multiple reference stations or not ?
- GPS with or without GLONASS ?
- denser network of reference stations ?
- transmission protocols in DARC.

SWEPOS ACTING AS REFERENCE NETWORK ON NATIONAL AND LOCAL LEVEL

Some ideas on how SWEPOS, probably densified, could act as a reference network both on a national and a local level, will be outlined in this section. Let us take a look at the time perspective 5-10 years. The RTK service in SWEPOS will be operational. Depending on how far the Ciceron project has lead this service in terms of accuracy and fastness, one of the two scenarios below could be possible. In five years it should be technically possible to work as in the scenarios below, but it will probably take five more years before a main part of the community is ready to fully work with the future reference networks.

Details will be measured by a combination of satellite based methods and terrestrial methods. With combined equipment details could be measured by both terrestrial techniques and with RTK-technique directly from permanent or temporary reference stations. This will increase the reliability sharply. Of cource a lot of details will just be possible to measure with one of the techniques and the techniques will complement each other. When enough points have been determined with both techniques, terrestrial measured details could be connected to the reference system with the free stationing method.

For some applications all details are measured with the same technique, satellite based or terrestrial. If terrestrial techniques are used, only the connection to the reference system is done by satellite based techniques.

Scenario 1

If the RTK service based on SWEPOS, the present 21 stations or a densified SWEPOS, will be as accurate and fast (determination of ambiguities etc.) as short range (< 10 km) measurements are, SWEPOS will be the only needed control network ! It should be used on national level as it is already today, but also directly for local surveying. Exceptions are areas where satellite techniques not could be used (e.g. tunnels) and for applications which need extremely high internal accuracy (better than 1 cm). In those cases local networks have to be established. The local networks should of course be connected to SWEPOS to get coordinates in the same reference system.

Scenario 2

If the Ciceron project shows that a higher density of reference stations is needed for getting centimeter accuracy than what is reasonable in a homogeneous national network, the scenario will be densification by local permanent reference stations where the user basis is big enough, and temporary solutions to the rest.

In areas where there are a lot of activities during a longer period, e.g. populated areas and larger constructing projects, denser networks of permanent stations will be established. The network has to consist of at least a certain minimum number of stations, in order to enable redundant measurements and maybe to take care of possible orientation errors. In five years receivers will be available that could take care of data from more than one reference station in realtime. As mentioned earlier this densification is preferrably done as a cooperation between the organisation responsible for the local survey and SWEPOS. There is a lot to gain in such coordinating, e.g. the system is open to all users and the maintenance will be less expensive. Prerequisites for such cooperation is that standard equipment, data formats and reference systems are used.

In sparsely built up areas the density of a national SWEPOS would be enough. For many applications this network could be used directly for local survey. If the accuracy demands are higher new temporary reference stations are established in connection with the local survey (detailing). For larger local surveys some kind of "temporary permanent" reference stations consisting of a container/vehicle with satellite receiver, transmitting equipment and power supply could be a solution. The measurements for the determination of the temporay reference station could either be done simultaneously with the local measurements or before. The latter case must be used in the case of setting-out. At present 24-48 hours observation time is needed for establishing a point with 1 cm standard error and 1-2 hours for 2-3 cm. In 5-10 years the observation time will be considerably shorter, maybe 30 minutes to a couple of hours. With a portable PC and a mobile telephone the static processing could be done out in the field. The temporary reference points should be marked if there is a reason to believe that they could be needed again.

Control networks where satellite methods not are appliable

The areas where satellite techniques are unusable will be fewer and smaller in the future, thanks to the larger number of satellites that could be used (GLONASS, GNSS), but there will still be such areas. SWEPOS has to be supplemented with networks for other techniques in those areas. E.g. in center of towns wall-marked control networks could be a good complement. The reference system for these networks have to be common with the reference system for the permanent reference stations. The networks could be connected to points, which are directly measured from SWEPOS.

CONCLUSION

SWEPOS is already today an alternative to traditional networks. It is used for aerial photogrammetry, forestry, agriculture, GIS, cadastrial survey, high precision geodesy and many avionics and maritime applications. For geodetic applications on centimeter level, the present observation time needed (2x24 hours or 1-2 hours depending on the accuracy demands) is too long in many cases. With better models etc., studied in the project Ciceron, and a possible densification, SWEPOS could in 5-10 years replace traditional networks in many areas. A requirement for this is that there are good conditions for using the national reference system locally, e.g. transformation formulas have to exist.

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