SAPOS

A Satellite Positioning Service of the German State Survey

SAPOS is a joined project of the Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV) and consists of a network of more than 250 permanently observing reference stations with national expanse that ensure the current accurate spatial reference based on the Europe-wide standardized reference system ETRS89. Within differential GPS measurements, users will be provided with SAPOS data on different accuracy levels in order to increase the position accuracy up to the centimeter and even millimeter range.

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Figure 1. SAPOS reference stations with location (real-time networking).

Basic Principles

-Differential GPS in Real-time

Within the process of differential real-time positioning, corrections are estimated by the comparison between measured pseudo-ranges and geometric ranges which are calculated from known coordinates. Thus, the effect of systematic errors will be minimized. The corrections for the mobile receiver are provided in a standardized form using a suitable communication medium. Mobile receivers can eliminate or greatly reduce distance dependent errors using the correction data, since it can be assumed that one finds comparable errors in the near surrounding of a reference station. Unfortunately, the errors considerably deviate between the mobile and the reference station. The reference station observations can represent the errors of the mobile station only with reduced accuracy, getting worse with increasing distance. Here, one speaks about a distance dependence of the error effects. The possible distance between mobile and reference station should be chosen according to the wanted position accuracy. With mean accuracy requirements in the order of 0.5 to 3 meter (code positioning), the possible distance can reach several hundred kilometers. The distance is mainly limited due to ionospheric effects for the highest accuracy demands in the order of 1 to 2 centimeters (carrier phase positioning). In case of low ionospheric activity, a distance up to 20 kilometers to the reference station is possible. In case of high ionospheric activity, the maximum distance to the reference station is limited to less than 5 kilometers. These values are strongly dependent of the quality of the used equipment (single or dual frequency receiver, antenna, data processing, etc.) and of the satellite geometry. Further distance dependent errors arise with an insufficient modeling of orbits and tropospheric delays.

-Real-Time Networking of Reference Stations

Distance dependent errors can be greatly reduced within a common processing of the observation data of a reference station network. This approach is commonly described as "networking". Here, the spatial alterations of the error components are calculated from the observations of a set of homogenously

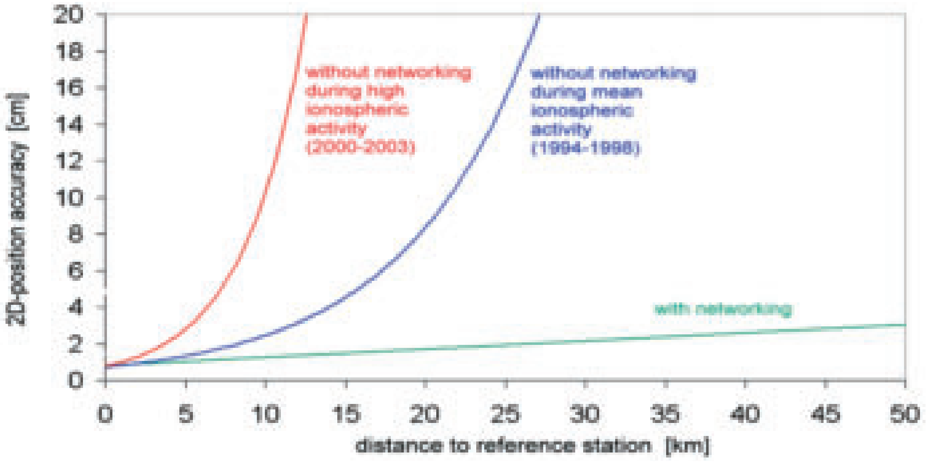

Figure 2. Achievable horizontal positioning accuracy depending on distance to reference station.

distributed reference stations with highly precise known coordinates. It's necessary and prerequisite for this approach to resolve the carrier phase ambiguities for the reference stations. A comparison of the measured pseudo-ranges between the reference stations and GPS satellites with the calculated ranges using their known coordinates enables the determination of ionospheric and geometric (troposphere and satellite orbits) residuals. These serve as base points for the calculation of linear planes (polynomial parametrization). Using this networking principle, even highest accuracy requirements in the order of 1 to 2 centimeters can be met with distances between 30 and 50 kilometers between mobile and the nearest located reference station. Thus, SAPOS users can obtain considerable economic profits. The results of the networking are currently provided as Area Correction Parameters ("Flächenkorrekturparameter" FKP) or Virtual Reference Station (VRS) correction data. Both methods can represent the results of the networking process taking distance dependent errors into account. Aside from the original single station corrections for each satellite, the FKP approach additionally provides linear FKP planes (polynomial parametrization) valid for a certain regional area. The mobile receiver (rover) has to read this network information and the single station corrections for a common processing (FKP individualization). Almost all modern geodetic receivers are capable to work up these parameters. The VRS approach generates and transmits correction data referring to a non-existing and therefore virtual reference station located directly aside the rover station. In a first step, the rover has to broadcast its approximate coordinates resulting from a single station adjustment to the network central office. Afterwards, the VRS correction data can be received, which is corrected for distance dependent errors to the greatest possible extent.

-Postprocessing

Original carrier phase observations of the GPS-receivers are the data basis for differential positioning both in postprocessing and in real-time. Using the available software, station and distance dependent error sources are handled with to real-time comparable methods and strategies. Finally, the solution of the carrier phase ambiguities is always the key for a high precise positioning. Generally, one differentiates the two approaches "Parameterelimination" (elimination of parameters) and "Parameterschätzung" (estimation of parameters). The first approach uses differenced carrier phase measurements as observables so that certain disturbing parameters are eliminated to the greatest possible extent. In contrast, the second method is based on non-differenced observations with the purpose of a strict state parameter estimation in order to present the reality most suitably. This approach is comparable to the networking process applied in the common analysis of reference station data in real-time. The postprocessing method is used for positioning applications with highest accuracy requirements (e.g. state survey, geodynamic investigations) in the range of a few millimeters even over very long distances. For this purpose longer observation periods are necessary. Besides those static applications also trajectories of kinematic objects (e.g. for aerial photograph measurements) can be determined subsequently ("post-mission") with high precision. If a user records satellite data with a GPS receiver in a permanent reference station network (SAPOS), the following analysis is carried out commonly with the data of the surrounding reference stations to aim one solution. The used format is RINEX. The simultaneous use of several receivers in several sessions is practically used for analysis approaches in terms of multi station or multi session solutions. In strict consideration of existing correlations high neighborhood accuracies can be achieved. Highest accuracies, e.g. for the derivation of precise height information, are obtained with static observation periods up to 24 hours, the use of external satellite orbit information and absolute antenna calibration values.

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Data Formats and Communication Media

-SAPOS Data Formats

The real-time services SAPOS HEPS and EPS use the RTCM format definition (actual version 2.3). RTCM defines several message types for different kinds of information. Thus, the provided data contents can be adapted to the requirements at a time. SAPOS HEPS may provide different message types depending to the user's requirements. All federal states agreed with a national stipulated data provision format using the

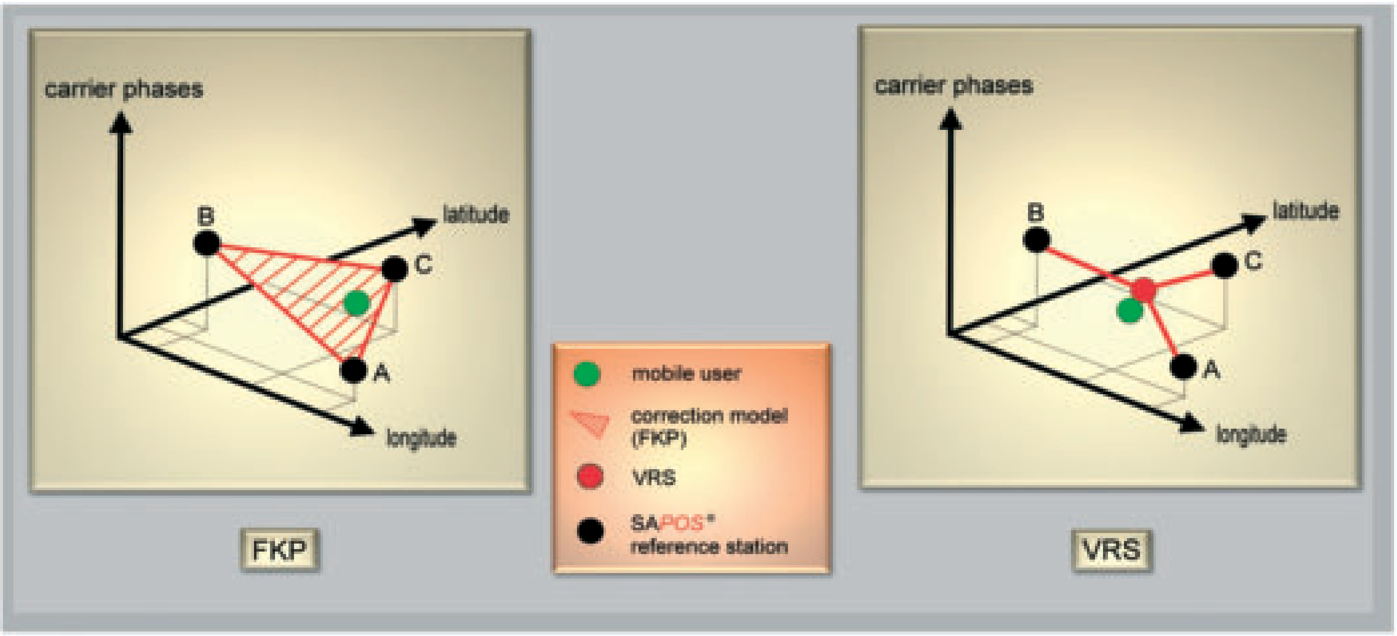

Figure 3. The representations of the networking results by means of FKP and VRS are illustrated exemplary for a commonly at three networked reference stations observed satellite. Accordingly, these examples are transferable to a higher number of networked reference stations.

RTCM message types 20 and 21 (compulsory or standard obligation including further message types) and additional networking information in form of FKP. The data has not to be encrypted and compressed, so that the receiver can directly process the information. Over and above that, the federal states may supply other message types (standard options) which meet possible different customer's requirements. These message types comprise the RTCM message types 18 and 19, and the provision of VRS correction data. Further on, encrypted and compressed data is provided with the RTCM-AdV format. The SAPOS EPS service uses pseudo-range corrections with additional information. The pseudo-range corrections are transferred using the RTCM message type 1. The RTCM message type 1 has been introduced with the RTCM version 2.0 and is used unmodified in the following versions. SAPOS employs internationally recognized standard formats. The post-processing procedures GPPS and GHPS use the RINEX format (actual version 2.1), which is an ASCII data format. It consists of a header and a body data section. General station information like station number and name, information about the GPS receiver and antenna, station coordinates, antenna heights etc. are given in the header. The epoch-wise observation information is written into the body section afterwards. The Virtual Reference Station (VRS) exists within GPPS as a special kind of data. The processing of this correction data is carried out comparable to the real-time networking using the whole reference station network, but the results are stored up in a special type of RINEX format. The data files look like standard RINEX files. Nevertheless, network correction information is included, which is normally not permitted and not part of the RINEX standards. The main advantage of this approach is the possibility for a fast and easy standard post-processing.

-SAPOS Communication Media

Standard broadcasting medium of SAPOS HEPS and actual European mobile radio standard is the GSM. This medium is used in Germany for the most positioning applications with SAPOS HEPS. It is almost area-wide available, cost-efficient and accepted. Optionally, HEPS data is transmitted via 2m band radio on demand. Momentarily, the introduction of a broadcasting medium based on the internet protocol (IP) is projected. Using this method SAPOS data can be transmitted via all IP-capable media. Today at the rover's site this is GPRS (General Packed Radio Service), in the future it will be UMTS (Universal Mobile Telecommunications System). The Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) has worked out the protocol definition NTRIP (Networked Transport of RTCM via Internet Protocol). Meanwhile, NTRIP became a RTCM standard. EPS data can be received Germany-wide via VHF (RASANT). Optional communication media are the GSM, 2m band radio and in the future also NTRIP. Normally, GPPS / GHPS data is transmitted using the internet. The user receives the data via FTP or E-mail. In addition the data is available on data carrier (e.g. CD-ROM) and partially provided via mailbox.

SAPOS Products

SAPOS provides the following fields of service with different features:

-SAPOS HEPS (High Precision Real-Time Positioning Service)

The network-based RTK service SAPOS HEPS enables a real-time positioning with an accuracy of 1-2 centimeter (horizontal) respectively 2-6 centimeter (vertical). The correction data is derived from carrier phase measurements and is broadcasted with data a rate of 1 second by mobile radio (GSM) or 2m band radio using the standardized RTCM format. Distance dependent errors can be considerably minimized by means of a networking process of the SAPOS reference stations. Thus, an increased accuracy and reliability of the positioning will be achieved. Possible fields of application: Engineering surveying, Geo-Information Systems (GIS) with higher accuracy requirements, real estate cadastre, supply and disposal, register of utility services.

-SAPOS EPS (Real-Time Positioning Service)

SAPOS EPS provides real-time positioning at an accuracy level of about 0.5 to 3 meter. Code corrections are transmitted nationally via VHF (RASANT). Additionally, SAPOS“ EPS can be used with a data rate of 1 second via mobile radio (GSM) or 2m band radio using the standardized RTCM format. Possible fields of application: Vehicle navigation, fleet management, authorities and organizations with security duties (BOS), Geo-Information Systems (GIS), maritime shipping, hydrography.

Figure 4. Real-time positioning with SAPOS HEPS.

-SAPOS GPPS/GHPS (Geodetic Precision/High Precision Positioning Service)
Post-processing analysis is necessary for the highest accuracy requirements. The SAPOS GPPS and SAPOS GHPS services enable a both horizontal and vertical positioning with an accuracy at the 1 centimeter or even millimeter level. The data is provided for the user in the standardized RINEX format via e-mail, internet (ftp-download) or on data carriers. The SAPOS GPPS service additionally allows the processing of a "near-online" solution, retrieving the RINEX data in the field. The SAPOS data with a data rate of 1 second is stored at least for 30 days. The SAPOS data with a data rate of 15 seconds is stored permanently on data carrier. If required, a data rate below 1 second can be provided on request. Possible fields of application: Aerial photogrammetry, laser scanning, fundamental geodetic survey, reference systems of the German State Survey, analysis of geodynamic processes.

The Central Bureau SAPOS

Due to the demand of customers in the Central Bureau, SAPOS was established at the LGN in Hannover on October 1, 2003. As a authorized contact person and negotiating partner the Central Bureau SAPOS is responsible for all customers who intend to use the products in more than one state. After the introduction of uniform standards this is another step in view of providing a Germany-wide uniform SAPOS service. The Central Bureau SAPOS carries out the following tasks:

- Nationwide provision of SAPOS data and responsibility for the issue of usufructs including the affiliated fees according to AdV resolutions
- Marketing of SAPOS data to nationwide users
- Support of the AdV with the coordination of nationwide activities
- Nationwide integration of SAPOS data
- Technical support for the cross national (Germany-wide) networking on request

In terms of an opened geodata market, the AdV would like to engage increasingly in partnerships of sale with private service providers. These Public Private Partnerships (PPP) are requested by the politics, since, speaking of national economy, it's useful and desirable, that the investments of the public sector for SAPOS are applied by as many users as possible. With regard to this aim, in 2002 the AdV and the Ruhrgas AG signed a Memorandum of Understanding (MoU) about strategic goals as well as about conjoint basic positions concerning the nationwide use and marketing of data by the Ruhrgas AG (positioning service ascos). In the meanwhile, this wanted partnership has been formally sealed through the signing of a PPP-contract between the Ruhrgas AG and the AdV in 2003.

Conclusions

In the age of satellite positioning, SAPOS has opened a new horizon for GPS measurements in Germany. By the use of the networking of reference stations high positioning accuracies are achievable even over great distances. The start of the European positioning system GALILEO (announced for 2008) will offer further prospects in terms of accuracy, availability and integrity. The interoperability of GALILEO and GPS will optimize satellite positioning and consequently enhance the quality of SAPOS.

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