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The Modern Technologies of DGPS and RTK Corrections Transfer**

1. Introduction

GPS technology is one of the basic geodetic techniques used in surveying, networking, engineering projects, measurements of ground and structural deformations. RTK (Real Time Kinematic) GPS technique provides information about the current position of a GPS antenna during an observation. RTK GPS measurements require that information about GPS signal corrections, emitted from the base station, should pass to GPS receivers. Information is normally sent by radio modems, which restricts the range of operational performance to 1–3 km (depending on the land features).

Extensive applications of this technology as well as the developments of wireless transmission systems have prompted the researchers to search for methods that would improve the range of corrections accessibility. The conventional corrections transfer format (DGPS/RTK) is specified by the international standard RTCM SC 104 [3]. Nevertheless, operators have their own binary standards for corrections transfers, to be used in radio modem transmissions.

This paper reviews the current solutions in the area of wireless technologies of RTK corrections transfer. Of major importance is cellular telephony which, thanks to connection to the Internet *via* GPRS, EDGE and shortly also UMTS, allows practically unrestricted range of transfer of GPS signal corrections [6–8, 10]. Research is underway to develop methods that would improve quality and confidence of real-time GPS positioning.

2. RTK and DGPS corrections transfer technologies

Despite similar requirements for DGPS and RTK surveys (Fig. 1), the accuracy of DGPS systems supported by code solutions will range from 0.5 to 1.5 m, the use of

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corrections in (RTK) phase monitoring allows for finding a point co-ordinates with the accuracy of 0.01 m. The application of correction transfer depends on the required accuracy in positioning and the available equipment. The basic method of RTK corrections transfer is by radio modem transmission. Since the operator needs the power capacities and frequency, corrections transfer is restricted by applicable legal permissions specifying the types and parameters of signals to be emitted. Power capacities of modems are usually restricted to 0.5–1 Watt whilst frequency approaches 450 MHz. More powerful transmission is allowed in rare cases only. That is why monitoring and surveying are restricted by engineering facilities and location of the base station, though attempts are being made to extend the range of RTK corrections transfer [9]. As conventional RTK measurements are now in widespread use, this method shall not be explained in detail.

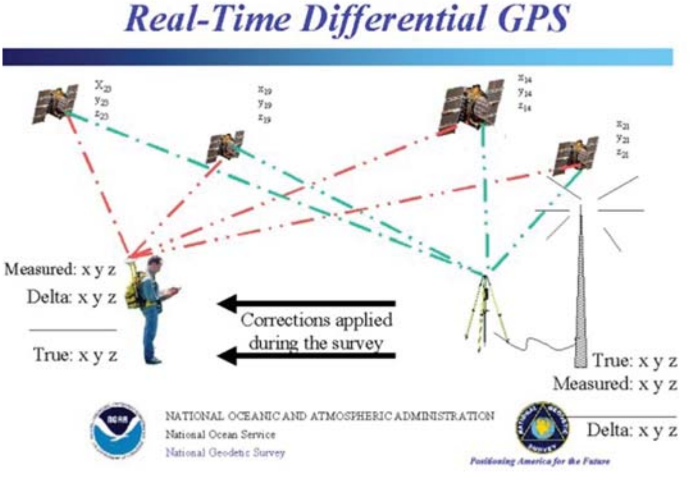

Fig. 1. Schematic diagram of DGPS/RTK surveys
Source: [1]

2.1. DGPS corrections transfer

DGPS corrections are a less accurate version of satellite signal corrections in GPS systems. They contain information about code measurements executed by the receiver, so they can be picked up even by tourists' GPS receivers. As the solution provides for lower accuracy, there are no strict constraints as to signal quality. Widely used methods of corrections transfer/ reception involve the signal emission from a geo-stationary satellites supporting the GPS system: WAAS (Wide Area Augmentation System) for the North America, EGNOS (Euro Geostationary Navigation Overlay Service) for Europe and MSAS (Multi-Functional Satellite Augmentation

System) for Asia and Japan, ensuring the coverage of vast areas on these continents. Corrections can be received via a wide range of code receivers, the method is chiefly employed in marine and aviation navigation.

Another method of corrections transfer is long-wave radio transmission, so they can travel large distance, particularly in marine navigation. Most lighthouses now have GPS equipment to allow for corrections emissions within the radius of several hundred kilometres (Fig. 2).

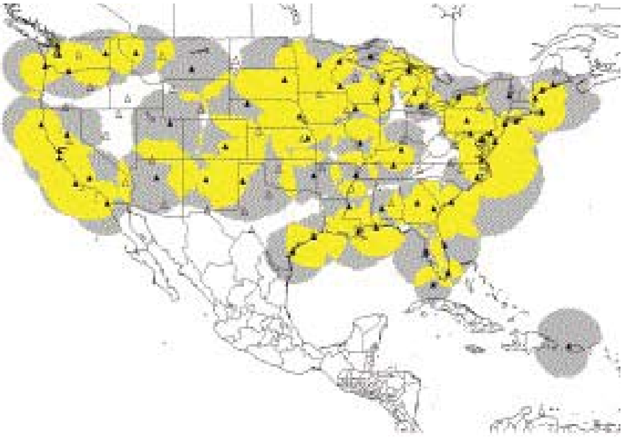

Fig. 2. Coverage range of DGPS lighthouse stations in USA
Source: [1]

Both methods require specialized GPS equipment. With satellite-supported systems, a receiver with implemented correction decoding is required. In the other approach, an additional correction-receiving device is needed to receive radio-transmitted DGPS signals.

One has to bear in mind that methods of corrections transfer outlined in further sections are widely applied in DGPS transmission, too. They are listed here to demonstrate their potential applications in GPS RTK systems.

2.2. Corrections transfer *via* Internet and GPRS systems

In these methods differential corrections are sent out from the base station in the RTCM format to a caster (computer), which further transfers the corrections via the Internet, utilising streamed data transmission protocols TCP/IP, UDP (supported by NTRIP – Network Transmission of RTCM *via* Internet Protocol) [10, 11]. In most cases operators of base stations allow the only the restricted access to RTK corrections via specialised equipment ensuring authorised data transmission only. An example is the ASG-PL (Active Survey Grid System) in the Silesia province (Poland), which is being extended to cover the whole area of Poland. Apart from unauthorised access (DGPS corrections), RTK corrections for area are available in VRS mode (Virtual Reference Stations) [6], whereby corrections values are interpolated for a virtual reference station, located near the field survey spot (Fig. 3). Interpolation utilises the satellite signals from the existing reference stations, within the range of RTK surveys (up to 35 km). This procedure is aimed to reduce the distance between rovers and the base station, which would vastly improve the accuracy. It is required, however, that information about a rover's approximate position should be transmitted to the ASG-PL computing centre to determine the virtual station's position. GPRS transmission can be used for that purpose as it allows the data to be transferred in the form of NMEA GGA code (containing the approximate position B, L on the ellipsoid WGS-84 – Fig 3b). Apart from devices playing the role of digital GPRS modems offered by operators, other hardware and software solutions can be applied, too. For example, specialist software can be implemented in a mobile phone supporting JAVA, or hardware implementations are possible on an IGTS device, manufactured by INS.

Apart from generating corrections for area on a virtual station, transmission via Internet helps to extend the applicability range in corrections transfer from existing permanent stations. A solution widely applied in Poland is a system developed within the framework of the project EUREF-IP. The authorisation procedure being complete, RTK corrections can be received no matter what the distance from the base station, though sufficient accuracy cannot be always guaranteed.

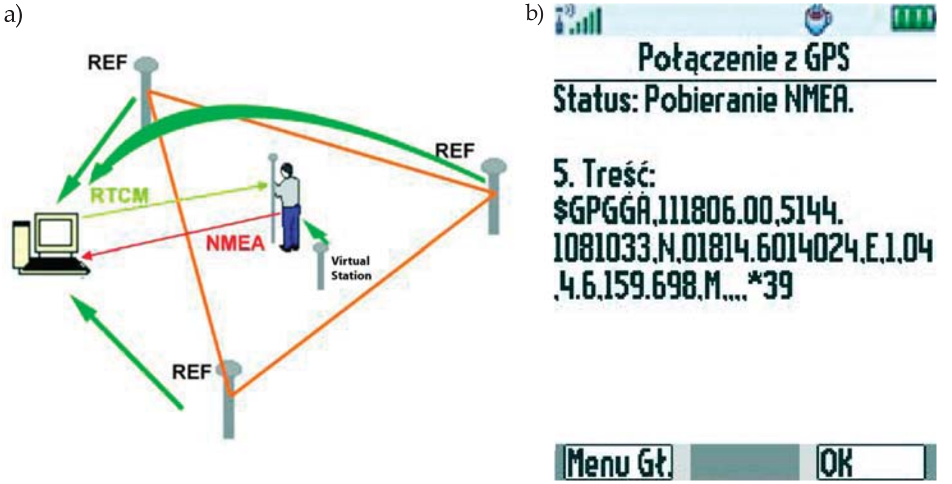

Fig. 3. Operating principle of VRS: a) generation of a virtual station inside the existing parametric stations; b) code NMEA GGA – application MobileNtrip f.4 to a mobile phone
Source: [12]

Tests reveal that 35 km is a limiting distance (as errors due to satellite signal propagation in the atmosphere can never be effectively eliminated).

Several options are currently available, there are software and hardware solutions, like in the case of VRS systems.

The application MobileNtrip allows for corrections reception and direct transmission to a GPS receiver. Simple software, offered free of charge by the authors of EUREF-IP: GNSS Internet Radio, enables the reception of corrections via Internet protocol TCP/IP, saving them to a disc file, transmission to external devices (GPS receiver) *via* a serial port or further redistribution using the TCP/IP protocol (Fig. 4).

Fig. 4. Program GNSS Internet Radio on a computer connected to Internet *via* GPRS using a mobile phone

The major drawback of such configuration is that it cannot be used in field measurements, yet it proves advantageous in GPS RTK monitoring [3–5] where a rover is never displaced. The best solution in this case would be constant access Internet. A modification enabling mobile measurements will be outlined in further sections.

An IGTS (INS GPRS Telemetric System – Fig. 5) is a device capable of replacing a radio modem that enables various types of GPRS transmission.

Fig. 5. RTK GPS system complete with a modem GPRS "IGTS"

This configuration provides [13]:

- Ntrip transmission (and selection of any caster– server of DGPS/RTK corrections),
- reception of VRS corrections for area,
- connection to a field base station and corrections transfer from any arbitrarily chosen spot,
- direct connection to the Internet – for example: browsing www pages.

Thanks to a compact housing, containing a set of batteries allowing uninterrupted several hours' operations, the device becomes one of the most interesting solutions available on the Polish market.

It is worthwhile to mention that GPRS transmission (no matter which device is used) is subject to a charge, payable to mobile network operators. Depending on the type of acquired data (data packages), this cost will range between ten and one hundred PLN per one working day. One has to bear in mind, however, that the chief benefit of RTK systems is that only one GPS RTK receiver is required, which vastly reduces the company's operating costs. Alternatively, when a company has more receivers, they can be used as mobile stations to facilitate and speed-up field measurements.

2.3. Internet transmission and conventional survey

Facilitated surveying and applications of advanced technologies to support conventional RTK configurations prompts us to ask the question how to transfer RTK corrections via the Internet in the cost-effective manner and fully utilising the available equipment. A possible solution is incorporation of conventional measurements supported by radio transmission with the devices connected to the global network via constant access systems or GPRS. When a radio modem is simply connected to a computer with Internet access and Ntrip is used in correction transmission, the corrections can be received at any spot (as connection to the Internet might be achieved via a constant access system, a stationary phone or a mobile). The corrections are then transferred to a radio modem via a serial port RS-232, whence the information about DGPS/RTK corrections is sent further. A laptop/computer connected to the Internet in configuration with and a radio modem make up a transfer station transmitting the corrections to conventional field devices, i.e. GPS receivers with radio modems, distant from the base station by less than 3 km. A similar solution is obtained when we replace a computer by a specific application (GNSS Internet Radio) via an IGTS device (Fig. 5). Connected to a radio modem, the device can execute the same task and its more mobile, because the base station emulated by the IGTS + radio modem array can be easily carried on rovers to spots where field measurements are taken, thus ensuring uninterrupted RTK transmission to GPS working stations. That vastly facilitates monitoring and surveys, no matter what the actual land features.

An obvious benefit of incorporating novel transmission technologies in conventional survey and measurements is that the available GPS RTK equipment is fully utilised, at the same time the costs of procuring state-of-the art technology of RTK corrections transfer can be minimised. A system configuration is shown in figure 6, the survey and monitoring procedure is shown schematically in figure 7.

Fig. 6. Base station emulation by an IGTS + radio modem configuration

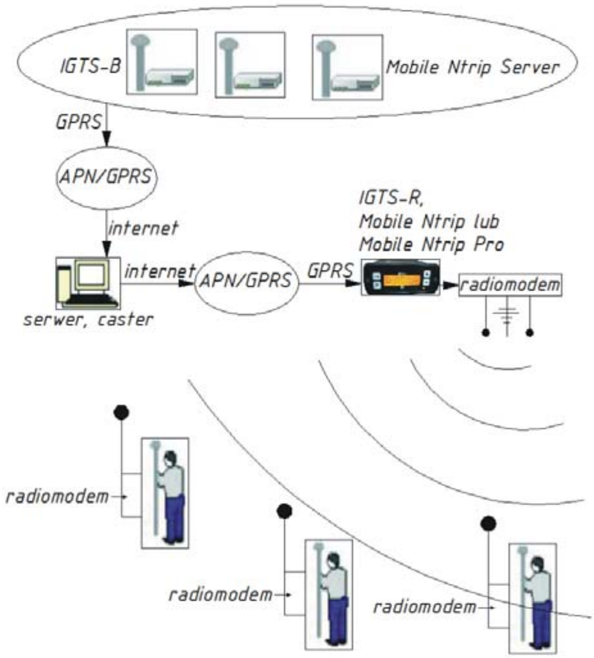

Fig. 7. Reception of corrections in GPRS and radio modem transmission

3. Conclusions

This study focuses on selected aspects only, to show the capability of RTK measurements over a wide area without the need of a reference station. A major benefit of GPRS transmission is its reliability whilst covering the whole country and hence limitations due to radio modem range are thus eliminated. No permissions are required to carry out RTK measurements on specified radio frequencies (apart from solutions integrating Internet transmission with conventional survey systems– see subsection 2.3). Certain payments are due to telecom operators, though these are traded off by improved operational performance and cost-effectiveness as no new receivers are required.

This is not an exhaustive review of all solutions that are currently available. There is also a wireless wide-range Internet technology WiFiMAX [7], enabling the access to the global network up to 60 km from the access points. This technology, however, is now in the design and testing stage and shall not be now explored in detail in the context of GPS signal corrections transfer.

Another technique to increase the distance from the base station in RTK surveys (up to 100 km) is referred to as Long-Range RTK. The main focus here is not on corrections transmission via the Internet, but on the type of information contained in the correction. This technique is not described in detail as the paper is limited in scope, yet it is worthwhile to mention that the use of information about the current atmospheric conditions (in the ionosphere and troposphere) in the vicinity of the base station and interpolation of the metrological data for the control point is a fundamental method of improving the accuracy and range of real-time GPS systems. Obviously these technologies (data transfer method and type of transmitted info) might be integrated in one solution. This is now looking to not a very distant future, it seems to be a matter of several months.

As the subject matter is really extensive, this is the first in the series of papers on state-of-the-art. RTK technologies.

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