Custom GPS-Correction Server for Real-Time Trajectography

Hervé Gontran, *Ecole Polytechnique Fédérale de Lausanne – EPFL (Switzerland)*

BIOGRAPHY

Hervé Gontran graduated in Surveying Engineering from the Ecole Spéciale des Travaux Publics, Paris in 2000. Then he joined the French National Institute of Geography where he developed a real-time application monitoring landslides. Since 2003, as a PhD candidate, he has been carrying out research about mobile mapping systems at the Geodetic Engineering Laboratory at EPFL.

ABSTRACT

Centimeter-level real-time kinematic (RTK) positioning is one of the most widely used surveying techniques. Broadcasting GPS-RTK corrections via Internet-based services has become a new communication procedure to achieve "instantaneous" positioning with high accuracy. This procedure generally involves a Virtual Reference Station (VRS), the data of which are derived from a network of GPS stations continuously linked to a control center. Its public implementation implies GDGPS (NASA Global Differential GPS) or NTRIP (Networked Transport of RTCM via IP Protocol) to disseminate 1-Hz data streams to stationary users over the Internet. Like their proprietary counterparts implemented by world-class GPS manufacturers, GDGPS and NTRIP are designed as high-quality positioning services that provide their clients RTK corrections whose format and pace are strictly defined. This restricts their use to surveying tasks for pedestrians. GPS-based trajectography in real time is an emerging technique requiring high-cadency data streams that needs a novel approach. This paper describes an architecture that fully exploits the generous bandwidth of the wireless Internet, so that the RTK users may remotely invoke custom applications on the server side. The emphasis will be on designing a multi-client broadcaster of GPS corrections that registers the trajectory of all the connected rovers in real time. Practical experiments will assess the tracking quality of fast moving rovers.

INTRODUCTION

Real-time kinematic GPS positioning is daily used in the fields of surveying, cartography, and land information systems. Such a technique involves a low-paced correction stream that is traditionally conveyed from a reference station to a rover by radio. The broad use of cellular networks has redefined the RTK communication process. In this context, rovers are frequently linked to a computing center that elaborates optimal 1-Hz GPS corrections from an array of reference stations. GPRS (General Packet Radio Service) or CDMA2000 (Code-Division Multiple Access v.2000) now offers the same reliability as the point-to-point cell phone calls, but with an even wider pass band. In this paper, a full exploitation of the GPRS pass band is investigated to enable high-frequency RTK corrections of custom format. Contrary to the solution offered by GDGPS or NTRIP, the described concept uses a bidirectional GPRS transmission: one way for the broadcast of RTK corrections towards the rover, the other way for the collection of the rover coordinates by a server. This enables a real-time trajectography, while at the same time analyzing the quality of the positioning.

TRADITIONAL GPS-RTK

The decade-old RTK process has gained a wide acceptance in geodetic and civil engineering. This technology is an extension of relative positioning based on the interferometric principle of exploiting precise carrier-phase measurements in real-time. The attainable accuracy is at the centimeter level provided that the reference station measurements are transmitted timely and reliably to the rovers and the integer ambiguities can be resolved correctly (Hofmann-Wellenhof et al., 2001).

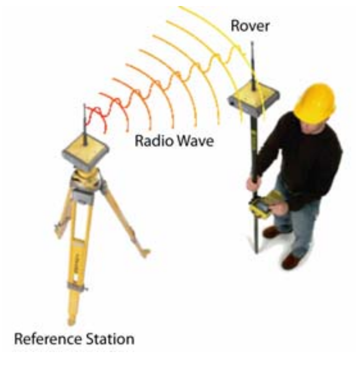

Figure 1: Radio link serving GPS-RTK.

Figure 1 illustrates a traditional implementation of GPS RTK. Low-power radio links allowed a fast expansion of GPS-based real-time positioning in the field since they do not require granting from the national telecommunications "organism". Such links rely on a direct transmission of digital signals, without modulation, via an undivided emission band. This means that only one message can be broadcast at once. Therefore, real-time comparisons of trajectories are out of reach of radio users. Moreover, the above-mentioned features cause some annoyances:

- troubles with frequency allocation,
- unpredictable interferences,
- short range due to low power.

WIRELESS NETWORK-ASSISTED GPS-RTK

Commonly used for voice and data transmission through GSM (Global System for Mobile communications) or CDMA, cell phones have quickly supplanted radios as the vehicle of GPS corrections. The coverage assured by national operators turns the cellular network into a low-cost choice media for RTK operation. When connecting to its counterpart, a cell phone establishes a link so that the wireless network is transparent to the data. This simulates a true point-to-point connection, as if the recipient of the call were directly connected to the application (or the peripheral) controlling the modem of the cell phone. Thus, any cellular connection procedure defines a specific line where the information exchanged between the two modems circulates.

In the geodetic field, first implementations of the cellular communication have involved a direct link between a GPS reference and a rover (Figure 2). Even if the pass band was proved satisfactory for high-dynamics applications (Skaloud et al., 2004), this method is not user-friendly since its auto-answer and connection keep-alive functionalities involve extensive knowledge of highly-variable Hayes commands.

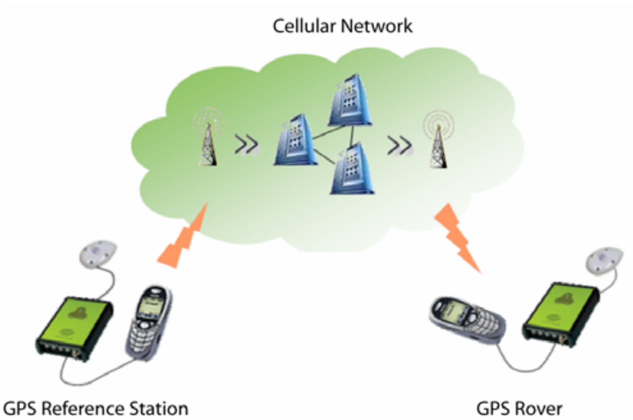

Figure 2: Direct cellular connection for GPS-RTK.

Apart from expecting GPS receivers to support any set of cell-phone commands, ease of use can be achieved by letting a "smarter" device handle the communication management. On the rover side, a serial modem managing the TCP/IP protocol stack allows a simplified connection to a GPS-correction broadcaster reachable by its phone number or its IP address. This broadcaster is usually a dedicated server that is either connected to a reference station by a serial link or to an array of permanent GPS stations via the Internet.

INTERNET SERVERS OF RTK CORRECTIONS

Due to the great bandwidth of the Internet, dissemination of RTK corrections over the Web represents an interesting alternative to the use of point-to-point links inherent in the radio and cellular networks. The Jet Propulsion Laboratory (JPL) at the California Institute of Technology was among the first to investigate an Internet-based global differential GPS structure (Muellerschoen et al., 2000) now called "NASA Global Differential GPS System". Using a world-wide network of 62 stations, GDGPS has been deployed to return GPS data in real time from remote receivers. It collects, edits, and compresses the raw GPS observables at the remote site. Packetized data are then transmitted via the Internet to the JPL processing center that produces precise GPS orbits and clock data. Both are formatted and compressed as corrections to the GPS broadcast ephemerides. Then they are provided via the Internet to authorized users (Figure 3).

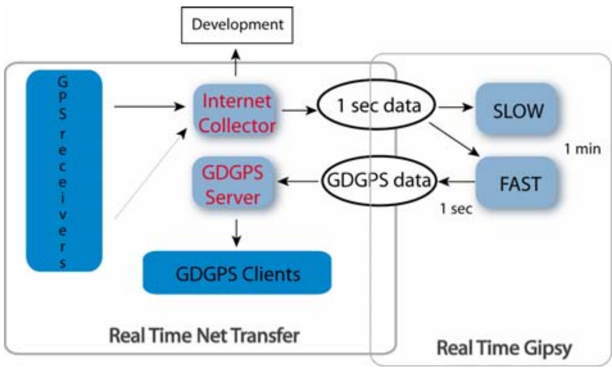

Figure 3: The NASA GDGPS system.

In the context of the European terrestrial reference frame, the Federal Agency of Cartography and Geodesy at Frankfurt (Bundesamt für Kartographie und Geodäsie) has developed a much more public-oriented technique for the exchange of GPS data over the Internet (Weber et al., 2003). This open, non-proprietary method termed NTRIP, encodes the RTK corrections for highly-efficient transmission over the Internet. It calls upon a substantial array of servers that allows the simultaneous connection of thousands of users (Figure 4).

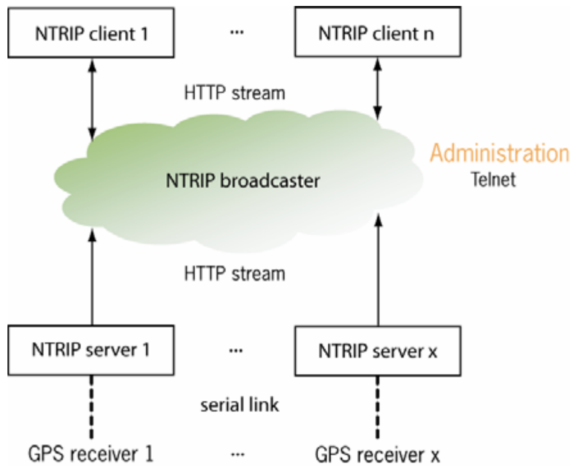

Figure 4: The NTRIP architecture.

Services open to general users such as GDGPS and NTRIP exploit the Internet infrastructure through the handling of thousands of simultaneous connections. However, they only involve GSM- or CDMA-compliant streams of 1 Hz RTK corrections, so that users do not really benefit from this broadband communication. Moreover, the adoption of RTCM 3.0 messages tends to constrain more data flow even if such messages propose complementary information such as FKP – Flächenkorrekturparameter (Wübenna et al., 2002). Based on this suboptimal use of the communication media, as well as on the difficulty to implement specialized applications on an NTRIP server, a research was conducted to design a custom GPS-correction server for real-time trajectography.

INTERNET SERVER FOR HIGH-RATE RTK

GPRS and CDMA2000 are radio data transmission services that use packet switching on traditional cellular networks to access the Internet. Their practical data speed of 50 kbps sets the way for high-rate RTK transmissions. Specific modems embed several Internet communication protocols and convert the TCP/IP correction stream back to a serial link, so that one could imagine connecting a rover to its reference station via a virtual serial cable. However, any device connected to cellular packet-switched networks undergoes dynamic IP addressing through a network address translation (NAT). This security process blocks incoming connections to the modems (Premji, 2005). Therefore establishing a direct Internet link between GPRS- (or CDMA2000-) enabled GPS receivers is impossible. Other issues arise in preserving mobility and in optimizing the baseline for the RTK computation. This implies that the reference station should be mobile and therefore cannot be physically connected to an Internet server.

A solution lies in the design of a relay server that broadcasts GPS corrections from outside the cellular network. This approach offers:

- independence from the cellular provider who can grant routable but highly expensive SIM cards,
- multicasting of the reference corrections to groups of rovers,
- development of add-in software for the server.

The implemented server is organized around three threads (T1, T2, and T3 in Figure 5) that are totally transparent to the exchanged data. This means the format and cadence of the corrections can be freely adapted to applications ranging from RTK-based setting out to the trajectography of high-speed vehicles. A classical producer/consumer pattern operates the server. While thread T1 initializes communication sockets and monitoring functionalities, T2 reads data from the reference and feeds a memory buffer, and T3 moves data from the buffer to one or several references.

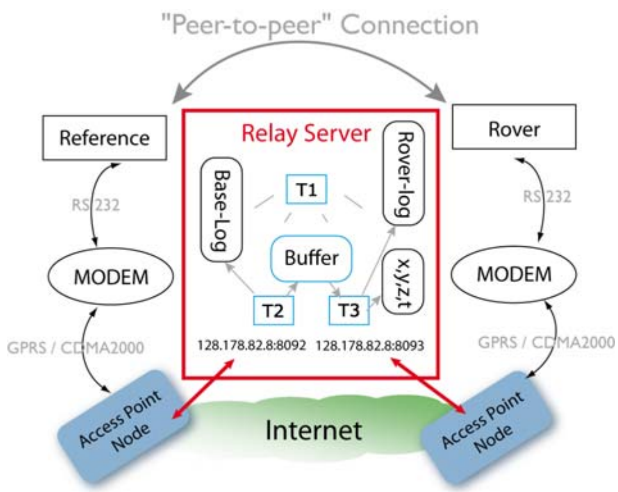

Figure 5: Custom relay server for GPS corrections.

Such threads simulate a peer-to-peer link between the base and the rovers. More specifically, whenever the relay server is launched, communication sockets are generated for the subsequent connections of the GPS reference and rovers. Once all receivers are authenticated using a challenge/response mechanism, the server retrieves their outside – routable – IP address. Then, it uses each address to transparently relay data between its clients while displaying the rover coordinates as a proof of simple add-in software design.

PRACTICAL EXPERIMENT

The custom server-based RTK computation was tested kinematically in a challenging suburban environment where many bridges and buildings block the GPS signals and a highway section “mistreats” the wireless link (surroundings of the EPFL near Lake Geneva, Switzerland). Complete loss of lock occurred on 4% of the 30-km-long journey.

The experimental scenario involved a vehicle whose roof rack supports two geodetic antennas with a lateral separation of 1.54 m. One antenna was connected to a Leica SR530 receiver accessing the 1-Hz NTRIP server of the Swiss Federal Office of Topography via a high-priority GSM link (Oliveira-Marques et al., 2005). The SR530 was configured to record position solutions at 5 Hz with a quality indicator better than 5 m. Considering the maturity of the NTRIP technology, the obtained trajectory was considered as a reference. The second antenna was linked to a Javad Legacy-GD receiver gathering 5-Hz RTCM 2.3 RTK corrections from the custom server over the GPRS network. The RTK engine of the Legacy-GD operated in an "extrapolated" mode, meaning that it extended the validity of previous corrections by extrapolating them to the current time tag. The computed solution at every epoch – i.e. the current one according to the receiver time – was broadcast through a 5-Hz NMEA-GGA message that also contained the latency of each correction. Figure 6 depicts the trajectories derived from the NTRIP messages (in red) and from the custom server data (in blue). It is worth noting that one might question an experimental setup involving two different types of GPS receivers, which reduces the comparability of the obtained trajectories. In fact, practical considerations dictated this choice: the Legacy-GD had not been upgraded to support RTCM 3.0 messages and it was deprived of a user-friendly GSM built-in modem. However, as has been found in previous tests, the kinematic performance of the two receiver types can be considered largely the same for the test trajectory.

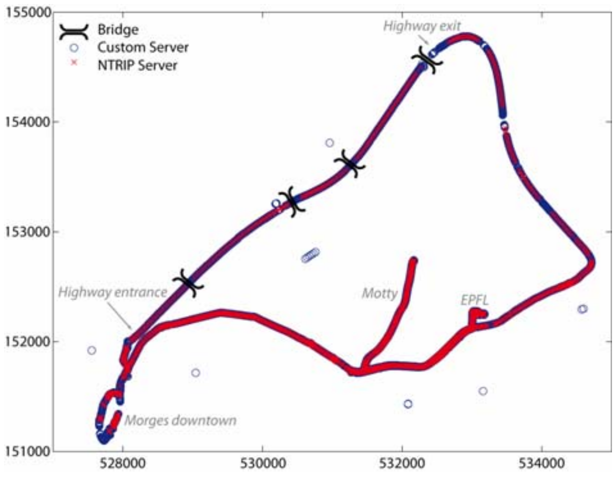

Figure 6: Trajectory results obtained by the NTRIP streaming system and by the custom server.

The accuracy of the vehicle trajectory based on the RTK corrections from the custom server is similar to the one obtained with the GSM-accessed NTRIP server. Outliers only occur after a total loss of lock due to occlusions mainly caused by bridges along the highway or the densely built-up downtown of Morges. Such features are absent in the SR530 recordings that are submitted to a position quality indicator. Moreover, in this challenging test, the percentages of RTK fixed, RTK float, and code solutions from the custom server (32%, 36%, and 32%, respectively) closely resemble those from NTRIP. However, at a speed of 80 km/h and beyond, the GPRS link to the custom server either fails to deliver the RTK corrections, or postpones the correction transfer; hence a significant degradation of the positioning accuracy arises.

One of the most significant features of the custom server is the high-paced broadcast of RTK corrections enabling a GPS receiver to compute an "unpredicted" solution at each epoch. Without this constraint, the SR530 − supposedly logging positions at 5 Hz − only achieves one recording per second. The latency of the RTK corrections derives from the processes they undergo, i.e.:

- computation by the GPS reference,
- encapsulation into a RTCM message,
- serial transmission to the relay server,
- TCP/IP encoding by the server,
- broadcasting via the GPRS network,
- TCP/IP decoding by a GPRS module,
- serial transmission to the rover,
- exploitation by the RTK engine of the rover.

Despite all these stages, the mean latency during the test is only 1.7 s, as deduced from the NMEA-GGA messages transmitted by the Legacy-GD. 10% of these messages even present an age of the differential corrections that is lower or equal to 1 s, which proves that sub-second broadcast of RTK corrections may be efficiently exploited. Figure 7 shows the pertinence of engaging the custom server to track a vehicle at high dynamics, particularly along narrow curves.

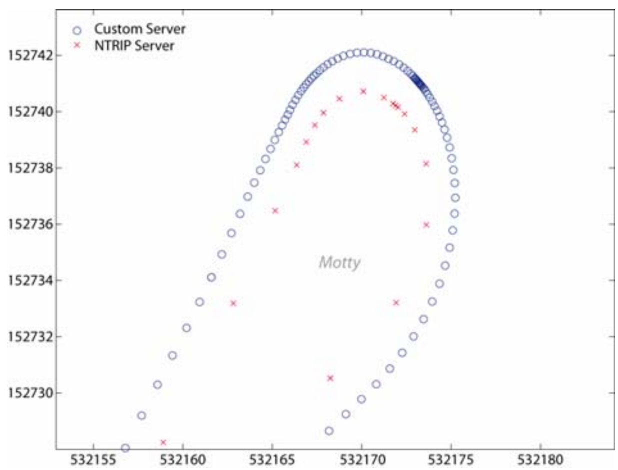

Figure 7: Comparison of tracking along a narrow curve.

Both Internet-based RTK distributions provide reliable results. In areas of excellent satellite visibility such as the village of Motty close to the EPFL, the obtained trajectories can be deducted from a quasi-translation of a traditionally-surveyed road axis (Figure 8).

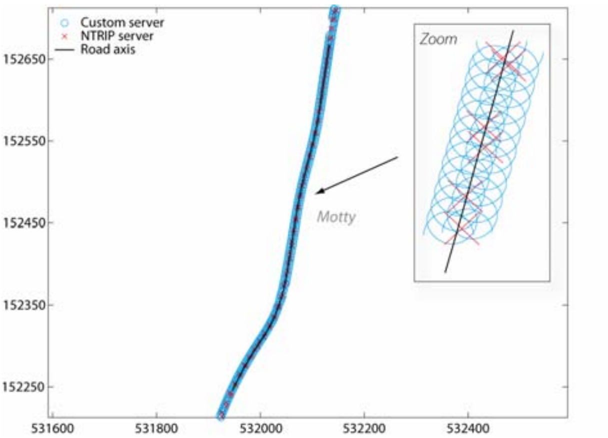

Figure 8: Reliability of RTK server-based trajectography.

Although the use of GPRS is dedicated for human beings and thus for walking speed, neither transmission blockage, nor disconnections were experienced during the kinematic test. Moving at increased speed on the highway causes a reduced correction rate and subsequently a degradation of positioning accuracy. This explains the outlying peak in the histogram whose classes depict the inter-antenna distance during the journey (Figure 9).

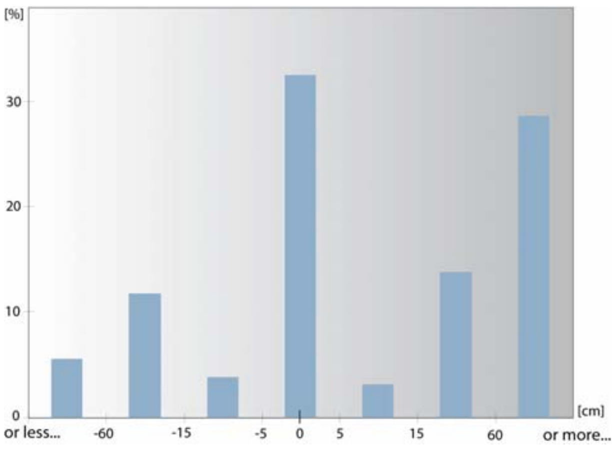

Figure 9: Deviation from the nominal inter-antenna distance during the 30 km-journey (0 corresponds to the nominal value of 1.54 m).

CONCLUDING REMARKS

This paper has introduced a novel method for a real-time acquisition of the trajectory of high-speed vehicles. Its advantages are:

- the excellent mobility of the approach, since the reference station, accessing the Internet through a small foot-print GPRS module can be placed virtually anywhere. Consequently, no VRS-like interpolation is involved for the production of RTK corrections.
- the transparency of the custom server with regard to the exchanged data. This involves a free choice of the cadency and format of RTK corrections with a high level of user-friendliness. Moreover, no special software is needed to unencapsulate these corrections, so that the GPS receivers only need to be connected to GPRS/CDMA2000 modules.
- the straightforward implementation of add-in software for the relay server, and a server-side Java applet that feeds a mySQL database with the rover positions gave promising results.

An Internet relay server of high-paced RTK corrections coupled with a GPRS-enabled rover contributes to a high-quality trajectography of a fast moving vehicle in real time. Advanced RTK engines can fully exploit sub-second old corrections that the GPRS network manages to transmit in satisfying proportion. Besides, this small foot-print apparatus may be easily introduced to other fields of trajectography such as tracking of skiers. New add-in software will automatically remove outliers by a spline modeling of the obtained trajectories. It will also exploit the continuous knowledge of the rover location to virtually move the reference station. This may avoid resetting the RTK engine. Finally, upcoming GNSS 2-based positioning (GPS3 and Galileo) as well as broadband communication links (EDGE and UMTS) should overcome the major drawbacks of this method.

ACKNOWLEDGEMENTS

I would like to thank Marco Lehmann for the fruitful discussions about Internet sockets and his willing help during the coding.

REFERENCES

Oliveira-Marques, M. de, Bonatti, I. S., 2005. Wireless Link Dimensioning: Priority versus Sharing. *Advanced Industrial Conference on Telecommunications/Service Assurance with Partial and Intermittent Resources Conference/E-Learning on Telecommunications Work-shop, 17-22 July, Lisbon, Portugal*.

Hofmann-Wellenhof, B., Lichtenegger, H., Collins, J., 2001. GPS – Theory and Practice 5th edition. *Springer, Wien New York.*

Muellerschoen, R. J., Bertiger, W. I., Lough, M. F., Stowers, D., Dong, D., 2000. An Internet-Based Global Differential GPS System, Initial Results. *ION National Technical Meeting, Anaheim, USA*.

Premji, A., 2005. Deploying Enhanced NAT Services in GPRS Networks. *Application note Juniper Networks Inc, USA.*

Skaloud, J., Gontran, H., Merminod, B., 2004. GSM-Distributed RTK for Precise Analysis of Speed-Skiing. *Proceedings of the 8th European Navigation Conference GNSS 2004, 17-19 May, Rotterdam, Netherlands*.

Weber, G., Dettmering, D., Gebhard, H., 2003. Networked Transport of RTCM via Internet Protocol, *International Union of Geophysics and Geodesy General Assembly*, *30 June-11 July, Sapporo, Japan*.

Wübenna, G., Bagge, A., 2002. RTCM Message Type 59−FKP for Transmission of FKP. *Geo++® White Paper Nr. 2002.0, 17 April*.