The Usefulness of Internet-based (NTrip) RTK for Navigation and Intelligent Transportation Systems

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BIOGRAPHIES

Marcin Uradzinski is an assistant professor in the Department of Geodesy and Land Management, University of Warmia and Mazury in Poland since 2006. He has been involved in GPS research since 2000. His main research topics are: integrated navigation systems and digital mapping. Currently, he is a postdoctoral fellow at the University of New Brunswick, where he carries out research related to Internet-based RTK positioning for precise navigation.

Don Kim is a senior research associate and a faculty member in the Department of Geodesy and Geomatics Engineering at the University of New Brunswick (UNB). He has a bachelor's degree in urban engineering, and an M.Sc.E. and Ph.D. in geomatics from Seoul National University. He has been involved in GPS research since 1991 and active in the development of an ultrahigh-performance RTK system for the past few years. He received the Dr. Samuel M. Burka Award for 2003 from The Institute of Navigation (ION). He also shared two IEEE/ION PLANS Best Track Paper Awards for 2006 and 2008.

Richard B. Langley is a professor in the Department of Geodesy and Geomatics Engineering at UNB, where he has been teaching since 1981. He has a B.Sc. in applied physics from the University of Waterloo and a Ph.D. in experimental space science from York University, Toronto. Prof. Langley has been active in the development of GPS error models since the early 1980s and is a contributing editor and columnist for GPS World magazine. He is a fellow of the ION and the Royal Institute of Navigation and shared the ION 2003 Burka Award with Don Kim, and received the ION's Kepler Award in 2007.

ABSTRACT

Current fast and reliable Internet services provide many advantages for worldwide GNSS users. Development of techniques using the Internet for streaming RTK/DGPS corrections allows mobile users to achieve high-accuracy positioning over both short and long baselines. Applications like GNSS Internet Radio are used for distributing raw GPS data and real-time corrections of GPS observations via RTCM protocols. NTrip (Networked Transport of RTCM via Internet Protocol), developed by the German Federal Agency for Cartography and Geodesy (BKG), is one of these Internet-based applications used for high-accuracy positioning and navigation. It enables streaming of GNSS data for stationary and mobile users by using the latest mobile communication technologies such as GPRS or UMTS in any area covered by a cell-phone network.

A particular NTrip-delivered stream can be accessed simultaneously by many clients using laptops, mobile phones or PDAs giving this approach enormous potential for supporting mass usage. Since NTrip became the leading standard protocol for GNSS data streaming, it has become popular in various public and private sectors. In the near future, dual-frequency GNSS receivers will be available at a moderate price, and therefore NTrip/RTK activities will be focused on dissemination of GNSS corrections for applications requiring greater accuracy like intelligent vehicle navigation systems and automatic machine guidance and control systems.

One of the topics that has long been a subject of research is improving the safety and efficiency of automobile transportation. Because GNSS/RTK techniques have great potential (enabling positioning to centimeter accuracy), researchers are developing tools to put them to practical use for controling vehicle motion for driver assistance. The combination of high-accuracy positioning information obtained from NTrip/RTK with high-precision INS sensors can support the latest concepts in vehicle-control systems (detection of relative vehicle position on a highway or collision avoidance).

In this paper, we focus on evaluating the performance of NTrip/RTK solutions for accurate and precise car navigation. Our approach is based on field experiments and the analysis of both the accuracy and availability of RTK data using mobile wireless transmissions. We investigate the advantages and disadvantages of each component in the navigation system. Car experiments were conducted on test routes under different driving conditions. To demonstrate the versatility of mixed-receiver systems, both NovAtel and Trimble mobile receivers were connected via a CDMA network to an NTrip broadcaster hosted by a Trimble NetR5 reference station receiver. Additional tests were performed using an

NTrip stream delivered by a free-standing mount point obtaining data from the same reference receiver acting as an NTrip server

INTRODUCTION

Car navigation and intelligent transportation systems have been long the subject of researchers to improve road traffic efficiency and driver safety. GPS is so far the most advanced element in the future of navigation. Much research is being conducted in the very important area of advanced lane change collision avoidance. Such an application, which is closely related to traditional car navigation systems needs to estimate the position of a vehicle with centimeter/decimeter level of accuracy. Due to these requirements, the GPS/RTK technique has been suggested for this application. This is definitely a more precise form of DGPS positioning since it is based on the phase measurements of carrier waves.

Noting the potential of RTK, the authors were interested in investigating its usefulness for vehicle tracking, lane keeping, obstacle avoidance and other advanced vehicle driving system needs. RTK could be used to help sharing precise position information among surrounding vehicles. Such vehicle-to-vehicle communication maybe effective in controlling distance and for collision avoidance [Omae and others, 2006; Du and Barth, 2008].

A conventional RTK system consists of a receiver at a known location (reference station), at least one mobile receiver (rover), and a radio link for sending data from the reference station to the rover receiver. Unfortunately, the radio link, playing the communication task, has a few drawbacks. The most important one is the typical short transmission range of low-powered systems caused by obstacles located in the path between a base station and a mobile receiver. Another drawback is signal interference, which can reduce transmission range and cause poor signal quality [Kim and Langley, 2003]. Facing all these drawbacks researchers developed systems for mobile Internet access like GSM (GPRS, EDGE or UMTS) which can easily provide a fast and reliable implementation of RTK/DGPS corrections into a GPS rover receiver in the area covered by a mobile phone network [McKessock, 2007]. NTrip is one of such protocols streaming GNSS data over Internet. It was developed by the Federal Agency for Cartography and Geodesy (BKG) in Germany. This service, providing real-time corrections for DGPS and RTK has proved to be a practical solution for GPS applications requiring a high level of accuracy.

NTRIP PROTOCOL

NTrip has been so far one of the best mediums transporting GNSS data. There are currently two ways of sending correction data. The first one has a possibility to handle RTCM corrections directly from a single base station. Another option is transfering all the observations using the Internet network to a central server, which after processing, broadcasts corrections via Internet to the client [Lenz, 2004]. The client runs e.g. “GNSS radio receiver” software on his computer (laptop, PDA) or on a cell phone, which is connected to the GPS “rover” receiver [BKG, 2008]. After updating the source table and choosing the nearest mount point, the device starts downloading RTCM stream corrections and sending them to the receiver (usually through the serial port).

GNSS DATA STREAMING AT THE UNIVERSITY OF NEW BRUNSWICK

Station UNB3 is one of the continuously operating reference stations located on the roof of the Head Hall engineering building, UNB, Fredericton. The station consists of a GPS+GLONASS Trimble NetR5 receiver and shares a Javad RegAnt choke-ring antenna with IGS UNBJ station. The receiver generates RTCM 3.0 messages for DGPS and RTK corrections, making them available via an NTrip server. This NTrip server has a potential to support many users. Numerous clients, after logging into the Internet Radio Receiver software, have direct access to the unique data source, called a mountpoint. Once the user is succesfully connected to the receiver starts getting RTCM 3.0 data streaming. The data stream is also available from an NTrip broadcaster called “NTripcaster” which is integrated between data sources and data receivers. After connecting to the caster opearted by BKG in Germany, the NTrip client has a choice to select UNB3 or another suitable mountpoint from listed NTripsource ID's.

FIELD TESTS OF NTRIP BASED RTK STREAMING

Car-following tests were carried out in April and July 2008 in order to check the possibility of the NTrip-based RTK operation and achievable RTK accuracy. The objective of the first test (April) was to check RTK results on the highway with different car dynamics, including fast acceleration and high speed. In this test the RTK stream was obtained from the NTripCaster located in Germany. The second test also in April was conducted in an urban environment (downtown Fredericton) for checking the severity of expected problems due to signal blockage (passing under the bridges) and data latency. In this case, RTK data was received dircetly from the receiver UNB3 mountpoint. Finally, the third experiment (July) was carried out in the combined environment (highway + downtown) to check the behaviour of RTK solutions in the areas mostly covered by tree canopies. Similarly to the second test, the data was received directly from the reference receiver's mountpoint.

EQUIPMENT AND SYSTEM CONFIGURATION

The GPS equipment used for the rover receiver with the first two RTK experiments was a dual-frequency GPS/GLONASS NovAtel Propak (OEMV-3) receiver. This receiver supports RTCM 3.0 data streams. In the third test a GPS-only Trimble R7 receiver was additionally used. All the receivers were upgraded to the latest firmware versions. To estabilish the Internet connection in the PC-laptop, a NovAtel Merlin PC720 Wireless PC Card was used. This card worked on the Bell-Mobility mobile network using CDMA technology. All of the receivers were connected to a Trimble Zephir antenna using an antenna splitter.

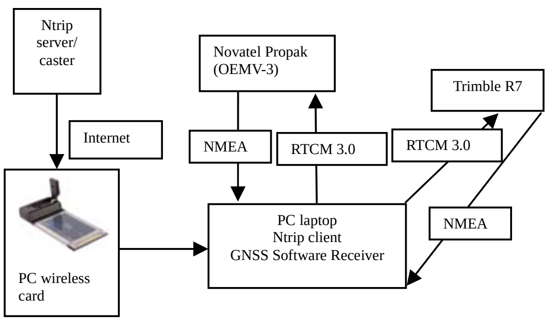

Fig.1 System configuration for NTrip/RTK experiments

Raw data recording and processing rate for both receivers was set to 1 Hz, with 10-degree elevation mask. Receivers were configured to work in the kinematic mode with “low latency” option. This option is suitable for applications in which positioning is required online at the epoch of receiving the reference data. The observations are processed regardless of the correction latency time, by using an internal buffer storing up to a few seconds of observations. The NovAtel receiver was set to be able to fix ambiguities with latency up to 30 seconds and the Trimble up to 10 seconds (by default). During the tests, RTK results and latency time was reported in the NMEA GGA message output, giving us a way to examine the quality of the position solutions.

Due to an RTK major operating constraint, which is base-to-rover range limit, all the tests were conducted not farther than 8 kilometers from the UNB3 base station. The rover antenna was mounted on the roof of a car, fastened by a magnet. Figure 2 shows the rover antenna mounting.

After the field surveys, the raw measurements recorded by all the receivers were processed in the office using GrafNav software. Precise coordinates from post-processing were used to compare with receiver RTK results.

Fig 2.The rover antenna mounting

TEST RESULTS

The first test was conducted ona a highway. Before reaching it the test started with a static period of six minutes. After setting all the equipment, estabilishing the wireless Internet connection, and only when the RTK fixed solution was stable, the car started to move towards the highway with an average speed of about 60 km/h. On the highway for a couple of minutes, the car was driving with an average speed of about 120 km/h and a maximum of 150 km/h. In this test, RTK corrections were received from the NTripCaster in Germany. The whole test lasted about 30 minutes.

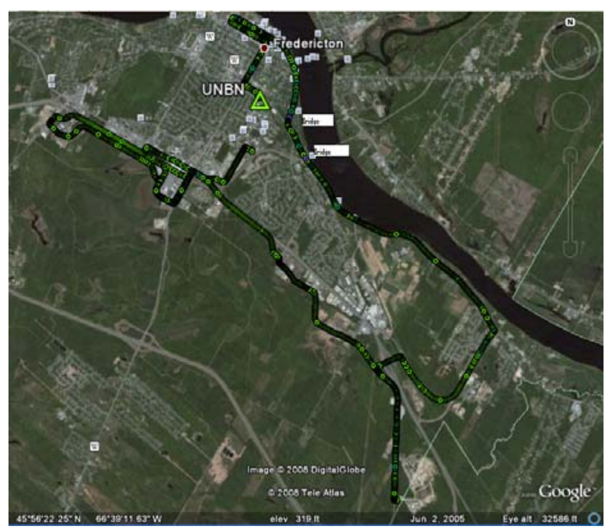

Fig 3.Test1 and test2 trajectory

During the test, the average corrections latency was 4 seconds. 99.5% of the RTK position solutions were fixed and 0.5% were float. Figures 4 and 5 show correction latency, number of both GPS and GLONASS satellites used and type of navigation solution during the test.

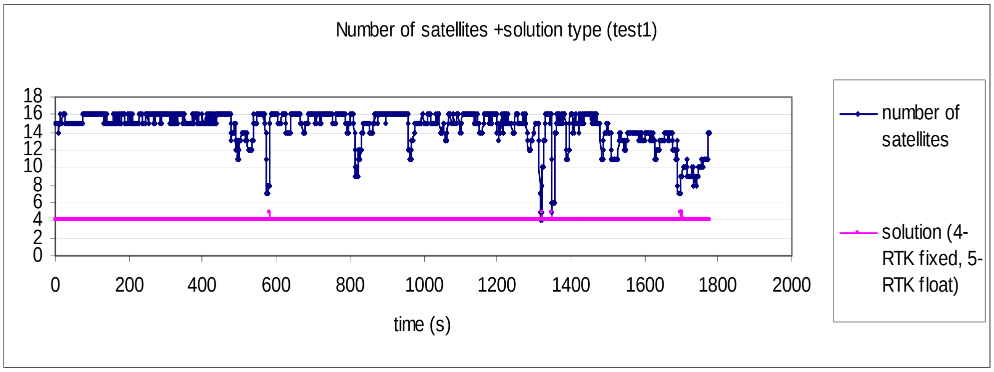

Fig 4.Number of observed satellites and the type of navigation solution (test1)

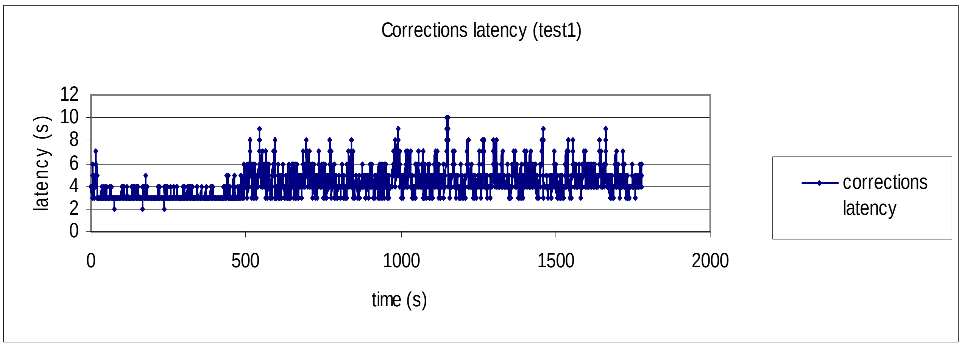

Fig 5.Corrections latency (test1)

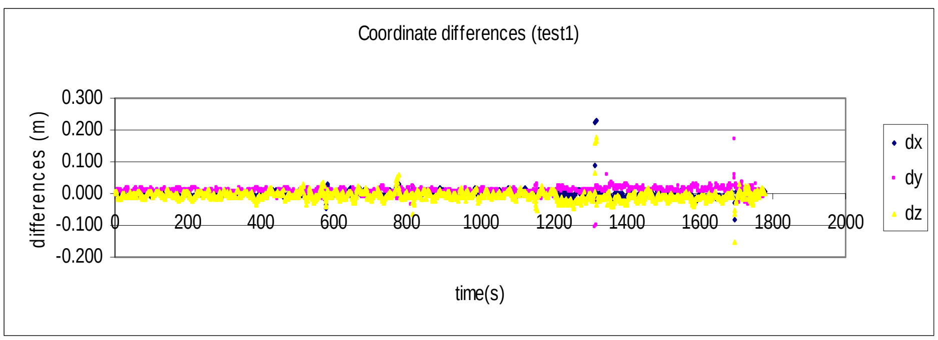

Fig 6.Coordinate differences (test1)

Table 1.Accuracy of RTK test1 results

	dx(m)	dy(m)	dz(m)
MIN	-0.083	-0.105	-0.155
MAX	0.231	0.173	0.175
AVERAGE	-0.001	-0.007	-0.007
STDEV	0.012	0.010	0.015

When comparing the post-processed positions to that of RTK test1 results, the differences were at the millimeter/centimeter level, and the maximum differences did not exceed 23 centimeters. It means that in spite of correction data latency of a few seconds, carrier-phase data were fully synchronized while processing the RTK navigation solution. The accuracy of the RTK results obtained in the first test is presented in Figure 6 and Table 1. Considering the car's high speed on the highway and receiving corrections from Germany, RTK results were very stable and centimeter level of accuracy was typically obtained.

The second experiment started in a forested area and ended in Fredericton's downtown. In this case, RTK corrections were received directly from the UNB3 mountpoint. Average latency was 1 second. Due to driving in the forested area at the begining of the test, the Internet connection was interrupted for 23 seconds. In spite of that, the RTK solution was still fixed with centimeter level accuracy.

Leaving the forested area, the car headed to the downtown area. Because RTK requires fast ambiguity resolution when loosing satellite tracking or having a poor signal, the goal of this test was also to check the behaviour of RTK solutions in the vicinity of bridges. In this test, the vehicle passed under two bridges and re-initialization times needed for fixing the ambiguities after the receiver passed under the bridges were 6 seconds (first bridge) and 5 seconds (second bridge) respectively. The complete test lasted about 26 minutes. During the experiment 96% of RTK solutions were fixed, 3% were float and 1% were not corrected (GNSS standalone pseudorange fix). Figures 7 and 8 show number of satellites, type of navigation solution and latency.

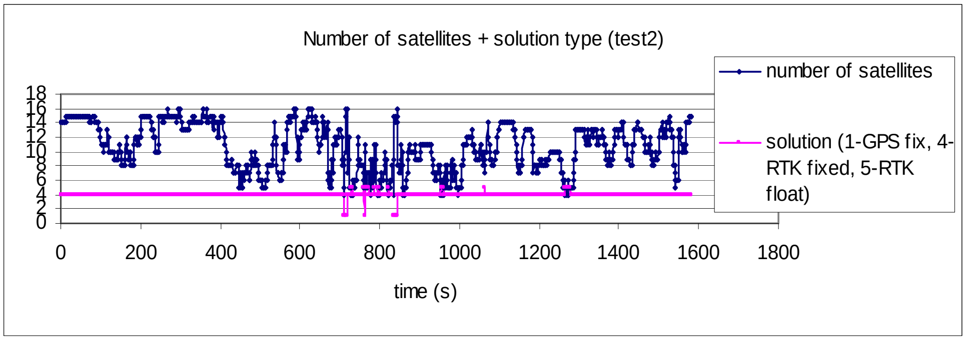

Fig 7. Number of observed satellites and the type of navigation solution (test2)

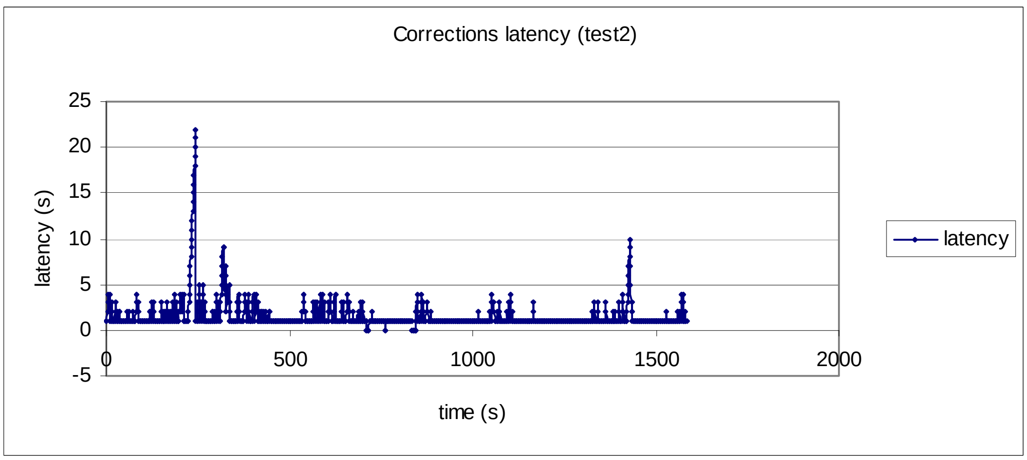

Fig 8.Corrections latency (test1)

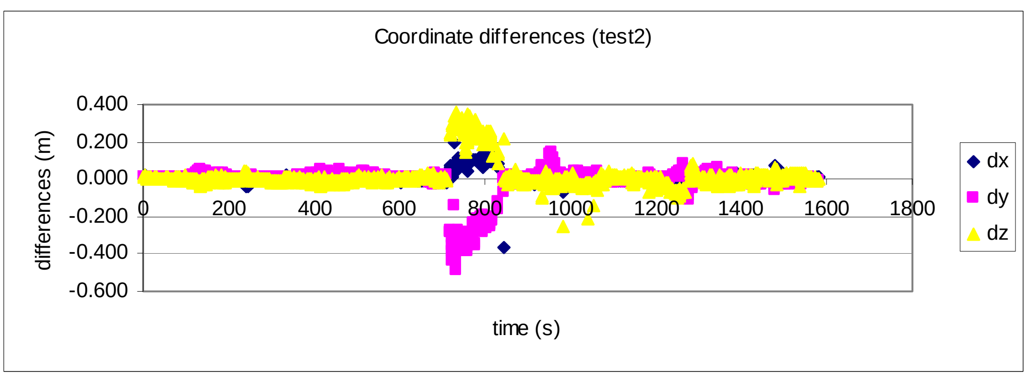

Fig 9.Coordinate differences (test2)

Figure 9 and Table 2 show the coordinate differences between RTK test2 position results and post-processed positions. Similarly to test1 results, they were at the centimeter level of accuracy. Average coordinate differences were between 1 and 3 centimeters and the maximum differences did not exceed 48 centimeters.

Table 2.Accuracy of RTK test2 results

	dx(m)	dy(m)	dz(m)
MIN	-0.366	-0.483	-0.251
MAX	0.196	0.146	0.356
AVERAGE	0.005	-0.011	0.012
STDEV	0.026	0.074	0.065

The last experiment was composed of two parts. The first one was conducted on the highway and the second one in the downtown area of Fredericton.

The GPS rover equipment used in this test consisted of Trimble R7 GPS-only receiver and GPS/GLONASS NovAtel Propak (OEMV-3) receiver. The major objective of this driving test was to check the following aspects:

1. performance of GPS-only receiver in the mostly forested areas and in the vicinity of bridges at speeds up to 100 km/h,
2. stability of wireless link

The two-scenario test was carried out on a similar test route to those used previously. The first part of it covered a highway with open areas or tree canopies on both sides. The signal outages seen on the picture are epochs not postprocessed by the software due to low number of satellites and poor satellite geometry.

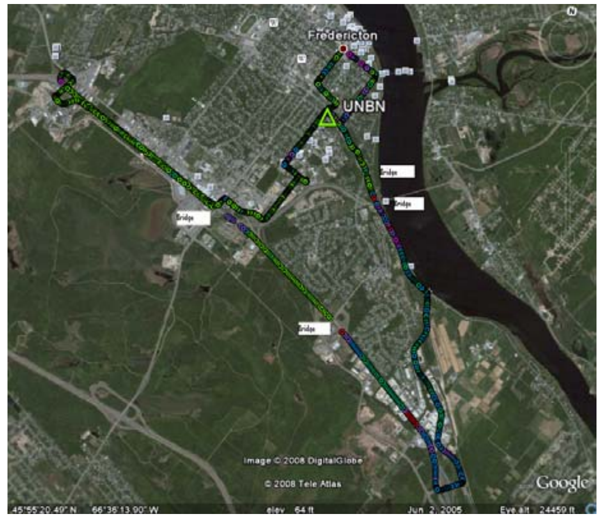

Fig 10. Test3 trajectory

The complete test lasted about 31 minutes. In spite of intensive tree canopies, for the whole trip 81.5% of the NovAtel receiver's position determinations were RTK fixed positions, 9% were RTK float and 9.5% were GNSS (GPS+GLONASS) standalone pseudorange solutions (under the bridges). Figure 11 shows number of observed satellites and type of navigation solution for this receiver.

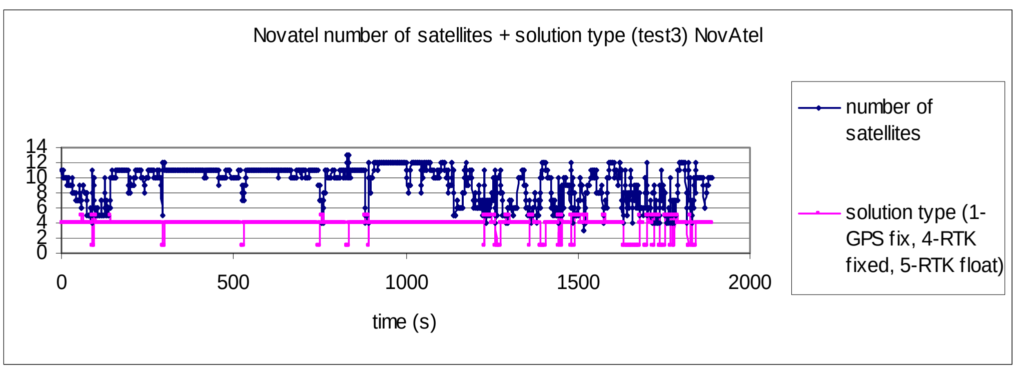

Fig 11. Number of observed satellites and the type of navigation solution for NovAtel receiver (test3)

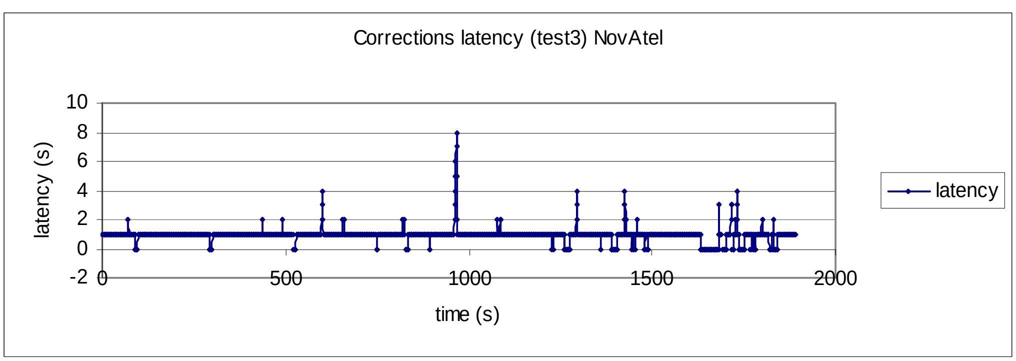

Fig 12.Corrections latency for NovAtel receiver (test3)

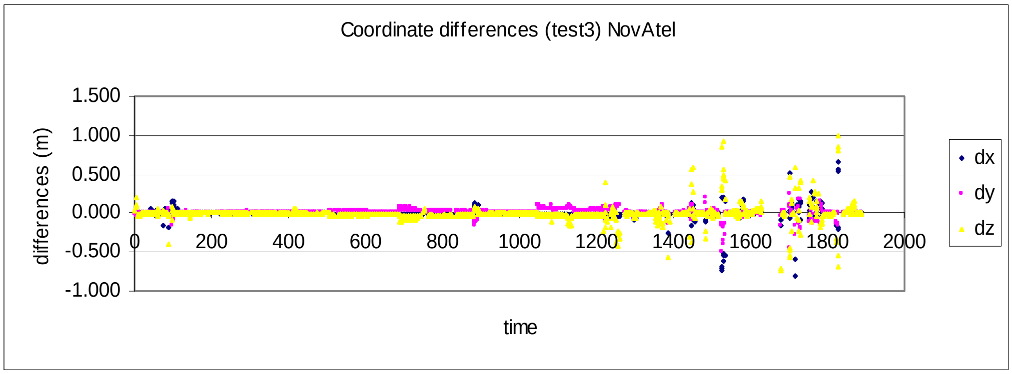

Fig 13.Coordinate differences for NovAtel receiver (test3)

Average corrections latency was 1 second. Zero values shown in the Figure 12 mean that the corrections were not applied to the navigation solution (number of satellites below 4, no interruption in Internet connection).

After comparing RTK results to the reference positions obtained by postprocessing raw data, the differences were at the centimeter level. Average accuracy for a whole test was about 2 centimeters and the maximum position difference did not exceed 1 meter in the downtown area. Figure 13 and Table 3 show coordinate differences for the Novatel receiver.

Table 3.Accuracy of NovAtel RTK test3 results

	dx(m)	dy(m)	dz(m)
MIN	-0.804	-0.503	-0.726
MAX	0.652	0.244	0.994
AVERAGE	-0.004	0.009	-0.007
STDEV	0.063	0.042	0.096

Results for the Trimble receiver were typically less accurate than for the NovAtel receiver due to lack of GLONASS capability. As seen in NovAtel results, additional GLONASS satellites used for RTK, in an integration with GPS satellites, increases the overall number of satellites. It helps speed up the ambiguity resolution and increases accuracy, especially in the downtown area.

Figure 14 presents the number of observed satellites and type of navigation solution for the Trimble receiver. The average number of satellites for the Trimble receiver was 7, where NovAtel had 10. During the test, 70% of the solutions were RTK fixed, 22% were RTK float, 7% were DGPS, 0.5% were standalone pseudorange solutions, and for 0.5% there was solution at all. Figure 15 shows correction latency, where the average delay was 1 second.

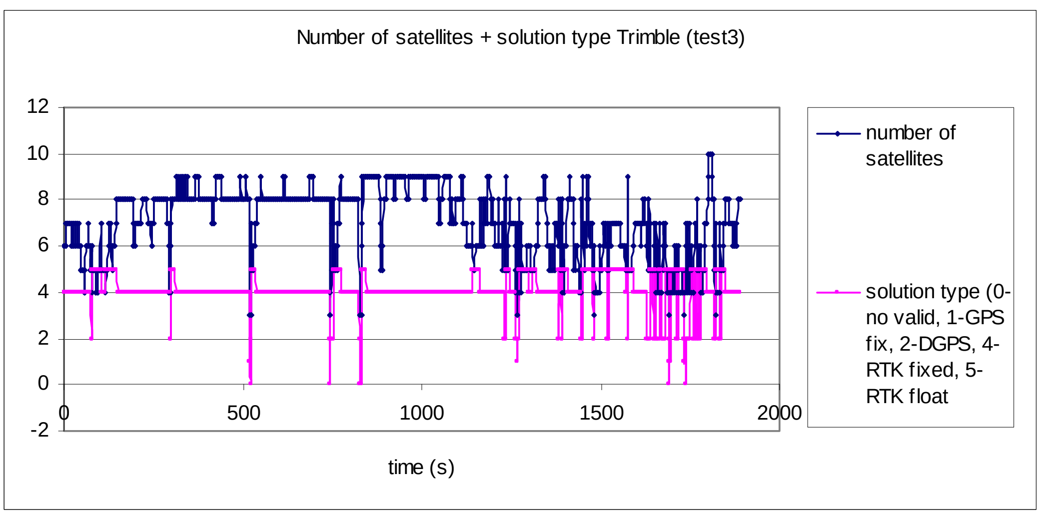

Fig 14. Number of observed satellites and the type of navigation solution for Trimble receiver (test3)

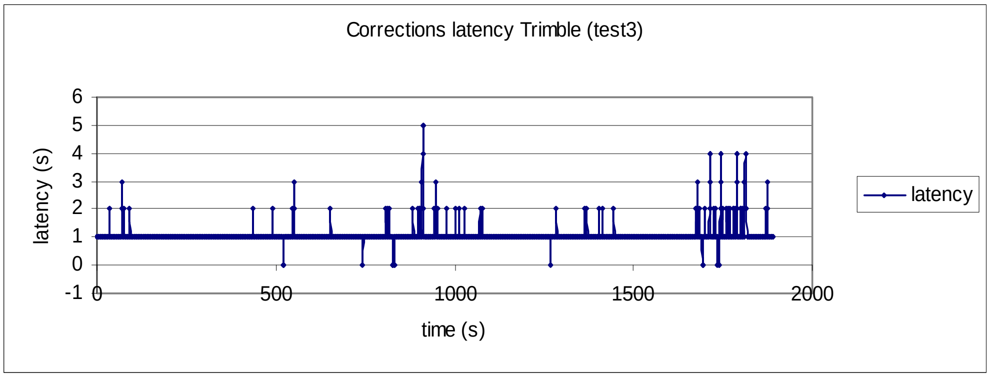

Fig 15.Corrections latency for Trimble receiver (test3)

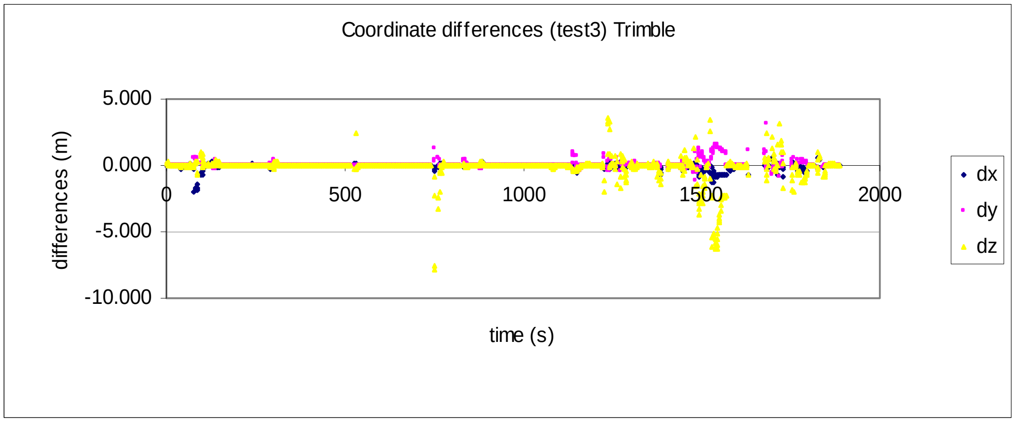

Fig 16.Coordinate differences for Trimble receiver (test3)

When comparing coordinate differences between post-processed reference data and Trimble results, the size of the differences can be put down to the decrease in the number of satellites (below four satellites in some places in the downtown area).

Generally, the RTK-delivered coordinates were very consistent on the highway, with differences ranging between a few millimeters up to few centimetres. Due to the low number of satellites and poor satellite geometry in the downtown area, differences there reached the meter level.

Table 4.Accuracy of Trimble RTK test3 results

	dx(m)	dy(m)	dz(m)
MIN	-1.978	-1.086	-7.804
MAX	0.578	3.177	3.585
AVERAGE	-0.052	0.043	-0.136
STDEV	0.224	0.265	0.860

CONCLUSIONS AND FUTURE WORK

The paper presented an Internet-based RTK system evaluation using NTrip protocol for providing accurate centimeter-level positions. The field experiments showed that the performance of the system is suitable for putting it to practical use for controlling vehicle motion for driver assistance.

While using a fast wireless Internet connection, latency of the reference data did not have a significant impact on the RTK results. The combination of GPS and GLONASS costellations was very precise, even in the urban environment. However there were some places where buildings and tree canopies were very harmful to navigation solution and they frequently blocked the signals of low elevation satellites. In such situations, a combination of high-accuracy positioning information obtained from NTrip/RTK with high-precision INS or other sensors could solve the problem.

Further research is planned to develop an additional functional system of determining lane position on highways. A system based on WiFi/radio communication between vehicles can be used for this purpose. Position, velocity and time data is computed in the GPS receivers and passed to the computers. Data such as position, velocity and raw measurements may be exchanged between surrounding vehicles using the two-way radio link. Integrating all mentioned functions into the rover system is our future goal to develop a precise in-vehicle navigation system.

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