GPS Signal Availabilityin an Urban Area - Receiver Performance Analysis

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ABSTRACT

GPS signal availability and DGPS positioning accuracy for two-dimensional navigation in two types of urban area, namely a downtown type with buildings up to 50 stories, and a residential area with two-story housing and tree-lined streets, is investigated using three multi-channel C/A code receiver types, including a fast-reacquisition narrow correlator spacing receiver. Signal availability, defined as the percentage of time during which HDOP I 5, is shown to be strongly dependent on the receiver signal tracking performance. Signal availability variations between receivers exceed 25% in some cases. The DGPS positions obtained with various receivers are intercompared and analysed as a function of satellite geometry and of the multipath environment. The narrow correlator spacing receiver is shown to produce superior positioning results, in terms of repeatability, as compared to the standard wide correlator spacing receivers used. Performance statistics based on repeated test runs are presented for the various scenarios described above.

INTRODUCTION

During the past few years, the comparative availability of Loran-C and GPS for vehicular navigation in urban areas has been investigated by the authors. A study conducted in 1991 using a 6-channel GPS receiver and a mul ti-chain digital Loran-C receiver showed that the availability of Loran-C was superior to that of GPS for a mixed trajectory consisting of downtown streets, 4-lane access roads and tree-lined residential streets. The test was conducted in Calgary under summer foliage (Lachapelle et al 1991). The lesser availability of GPS was attributed to a partial constellation available at that time and to the relatively slow reacquisition time of GPS signals during short periods of visibility behveen buildings.

In June 1993, the same trajectory was re-observed using the same Loran-C receiver technology and a narrow correlator spacing C/A code receiver, nameIy the NovAtel GPSCardTM (LachapeIle et al 1993). The major advantages of this lo-channel receiver are a relatively fast reacquisition time and an effective code multipath rejection capability (Cannon & Lachapelle 1992, Van Dierendonck et al 1992), which might be important in urban canyons. The relative availability of GPS and Loran-C (HDOP I 5) determined from this test is given in Table 1. The results are the opposite from those obtained in 1991. The availability of GPS is superior to that of Loran-C for each type of street selected. An analysis of the results also showed that the use of the best six satellites (minimum HDOP) among the satellites tracked resulted in nearly the same level of availability as that obtained with all the satellites tracked.

In order to determine the impact of GPS receiver technology on signal availability and accuracy, another test with several GPS receivers was performed in August 1993. The results of this test are reported herein.

Table 1: **GPS**[1] and Loran-C Availability Statistics June 93 Test

Trajectory	GPS	Multi-Chain Loran-C
Entire Traj.	88-93%	56-76%
Downtown	60-77	14-29
Residential	97-99	83-99

[1] **Using** NovAtel GPS Card TM

GPS RECEIVER SELECTION AND FIELD TESTS

Three C/A receiver types were selected for the August 1993 test, namely (1) the NovAtel GPSCard™, (2) a commercially available 6-channel standard (wide) correlator spacing receiver , and (3) another commercially available 6-channel standard correlator spacing receiver. Receivers (2) **and (3)** became available during the past four years. All three antennas have a relatively high gain near the horizon. Two receivers of each type were used to operate in differential mode. The three receiver types were tested simultaneously and the **antennas** were mounted on the same vehicle, some 50 cm apart. Three runs were made on August 17, each lasting approximately 1.5 hours. The trajectory, which was identical in each case, is shown in Figure 1. The GPS time tags shown in this figure correspond to the first run which began at 9:45. The first and second runs began at 18:00 and 19:45, respectively. The downtown city core, which is located around 232750 s in Figure 1, has buildings of up *to 50* stories. The residential area selected consists of tree-lined streets where GPS signals may be shaded by the canopy. The three monitor stations were located on the roof of the Engineering building of The University of Calgary.

Trajectory

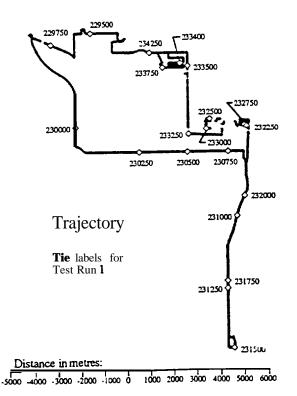**Tie** labels for
Test Run l

Distance in metres:

Figure 1: Trajectory Used to Test GPS Signal Availability With Three Receiver Types

The maximum distance between the monitor stations and the vehicle did not exceed 15 km. The theoretical GPS availability during the test runs was satisfactory. The number of satellites above 5' ranged from 7 to 9 and the corresponding HDOP was $\leq$ 1.5. The GPS measurements were collected every one second and the differentially corrected data were post-processed using The University of Calgary's C^3NAV^{TM} software. The heights were resolved at each point instead of being held fixed to an approximate value in order not to bias the differentially corrected positions. An exception to this was made when the GDOP was greater than 5 or when only three satellites were available. In such cases, the height was held fixed to the average of the five previously estimated heights that were obtained with unconstrained solutions.

ANALYSIS OF RESULTS

The first performance criterion analyzed is GPS availability (which is defined herein as a sufficient number of satellites to obtain an HDOP $\leq$ 5) and is summarized in Table 2 for each of the three receiver types used. The differences in availability between the GPSCard™ and the other receivers exceed 25% for the downtown area. For the residential area, the differences range from 7 to 69%. The consistency between runs is highest for the GPSCard™, with a maximum difference of 18% between runs **#1** and #2 in the downtown area. The corresponding differences for the other two receivers reach 67%. These differences are due to the effect of different satellite constellations and signal tracking performance, in particular to the signal reacquisition delay.

The number of satellites tracked by each receiver as a function of time during test run #l is shown in Figure 2. The corresponding HDOP's are shown in Figure 3. The GPScard™ tracks the maximum number of satellites available, namely eight, during the part of the trajectory between GPS time 231100 and 232100 seconds. During the same time, receiver 2 tracks its maximum of six. The HDOP is however similar in both cases, except for more frequent dropouts in the case of receiver 2. The major disadvantage of receiver 2 therefore appears to be a slower signal reacquisition time and less stable signal tracking under interference. Receiver 3, which also has six channels, could not generally track more than four satellites, even during periods when the horizon was relatively clear. During the downtown portion of the test **run,** receiver 3 lost the signals **on** most

Table 2: GPS Availability Statistics (%) - August 93 Test

Test Run #	Trajectory	Receiver Type		
		1 (GPSCard™)	2	3
1	Downtown	51	16	40
	Residential	98	91	78
	Entire Traj.	88	67	73
2	Downtown	69	39	43
	Residential	100	68	61
	En tire Traj.	92	66	75
3	Downtown	57	31	35
	Residential	92	24	23
	Entire Traj.	88	51	60

satellites for some seven minutes. Signal reacquisition times with this receiver are comparatively slow. In the residential area, where most of the streets were tree-lined, the GPSCard™ proved to be superior to the other two receivers, with an availability of 92 to 100%.

The second performance criterion investigated is the accuracy of the differentially corrected GPS positions of the vehicle. In the absence of multipath, the rms accuracy in each of the coordinates would be expected to be at the 50 - 100 cm level for the GPSCard™ and at the 3 m level for the other two receivers. Since no positioning system was available onboard the vehicle to obtain independent reference positions, the method used here to obtain a qualitative estimate of the position accuracy was to intercompare the GPS-derived trajectories obtained during each of the three test runs. This comparison provides a reliable estimate of the across-track position errors. The horizontal positions obtained during the three test runs in the residential and downtown areas are shown in Figures 4 and 5, respectively.

In the residential area, the across-track repeatability of the GPSCard™ DGPS positions is generally better than 5 m, except in a few isolated cases where it reaches 10 m. In the case of the other two receivers, not only are there many positions completely missing due to signal shading by the tree canopy, but the across-track errors between test runs exceed 50 m, especially in the case of receiver 3.

Figure 5, which shows the corresponding results for the downtown area, also show the approximate positions of the streets. The across-track GPSCard™ positions errors are due to multipath caused by the high buildings. In the case of the two other receivers, fewer positions are available and their across-track errors exceed 50 m in some cases. Figure 5 also shows that the fixes are grouped in clusters, with few or no positions between the clusters.
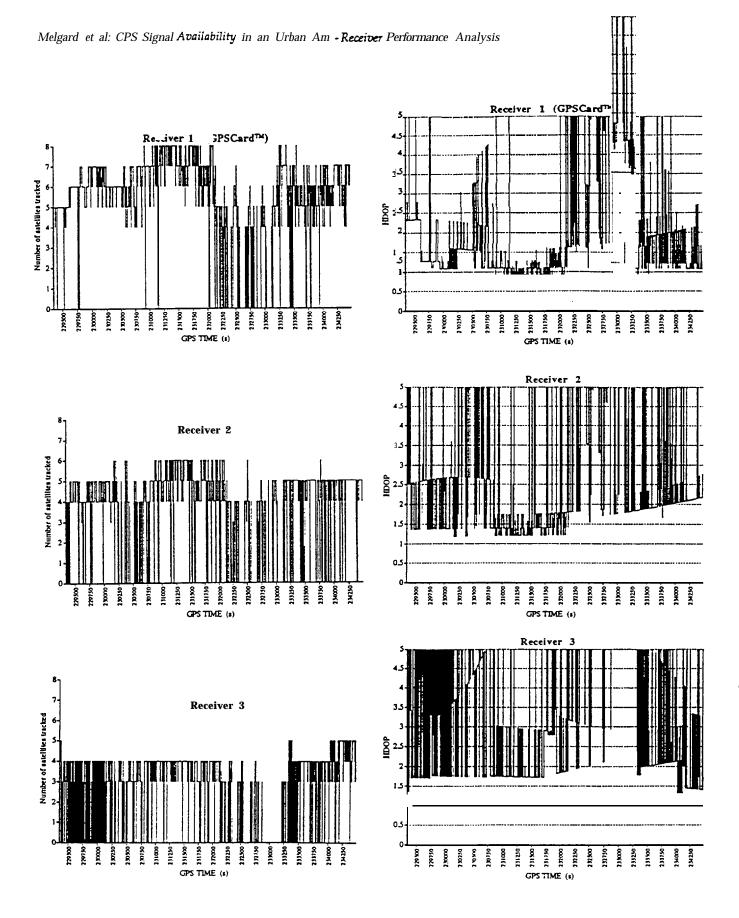
Figure 2: Number of Satellites Tracked During Test Run #2, 17 Aug 93

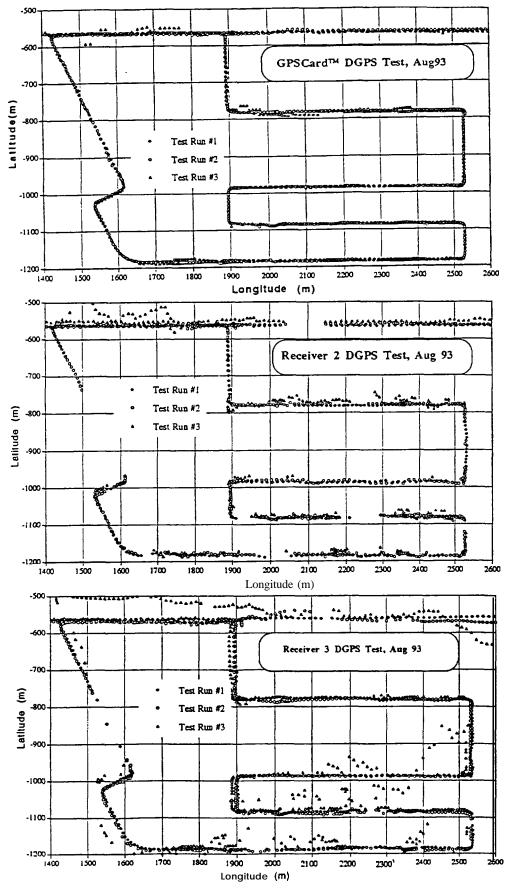Figure 3: HDOP's Based on Satellites Tracked During Test Run #2, 17 Aug 93

Figure 4: GPS Repeatability in Residential Area

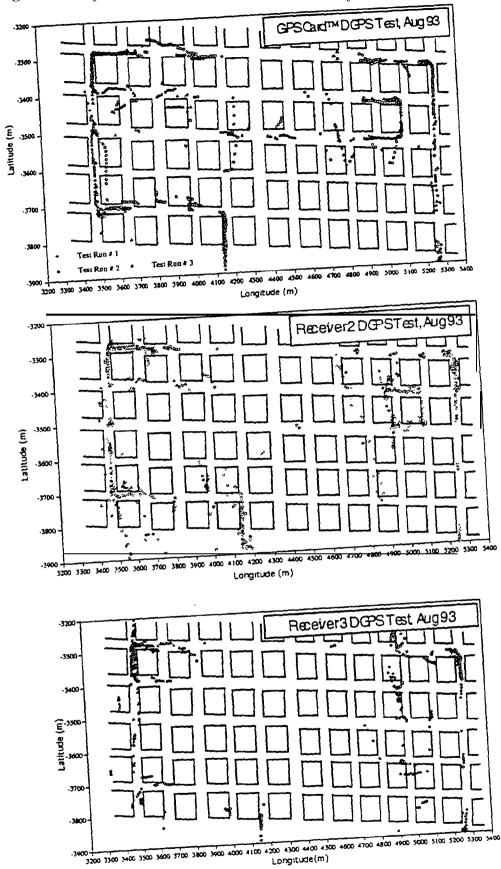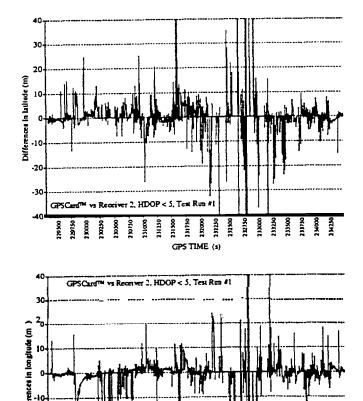Figure 5: GPS Repeatability in **Downtown Area**

The along-track errors were of the same order of magnitude as the across-track errors. This can be seen in Figure 6 which shows the latitude and longitude differences between the GPSCard™ and receiver 2 for test run #2. The GPS epochs can be correlated to the location of the vehicle by using the GPS time tags shown in Figure 1. In the downtown area, the vehicle was moving mostly in east-west directions between epochs 232250 and 233250 s. The longitude differences shown in Figure 6 during that portion of the trajectory are therefore due to along-track errors. These exceed 40 m in some cases. The latitude differences are of the same order as the longitude differences.
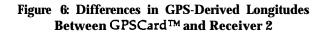
CONCLUSIONS

The analysis of the test runs presented here demonstrates that in a urban environment subject to much signal shading, the differences in GPS signal availability between different receivers can be as large as 60% (as shown in Table 2). The results also demonstrate the effectiveness of narrow correlator spacing technology in reducing the position errors caused by multipath from buildings in urban canyons.

REFERENCES

CANNON, M.E., and G. LACHAPELLE (1992) Analysis of a High Performance C/A Code GPS Receiver in Kinematic Mode. Navigation,39, 3, The Institute of Navigation, Alexandria, VA, 285-299.

LACHAPELLE, G., B. TOWNSEND, M.E. CANNON, and D. HALAYKO (1991) GPS and Loran-C Signal Availability for Urban Navigation: A case Study. Presented at VNIS91 IEEE International Conference, Dearborn, MI, October 20-23.

LACHAPELLE, G., B. TOWNSEND, H. GEHLJE, and M.E. CANNON (1993) Integrated GPS/Loran-C for Vehicular Navigation in Urban And Mountainous Areas. Proceedings of IEEE-IEE Vehicle Navigation and Information Systems Conference, IEEE Catalogue #93CH32854, pp. 456459.

Van DIERENDONCK, A.J., P. FENTON, and T. FORD (1992) Theory and Performance of Narrow Correlator Spacing in a GPS Receiver. Navigation, Vol. 39, No. 3, The Institute of Navigation, Alexandria, VA, pp. 265-283.

Figure 6: Differences in GPS-Derived Longitudes Between GPSCard™ and Receiver 2