GPS VERSUS LORAN-C FOR VEHICULAR NAVIGATION IN URBAN AND MOUNTAINOUS AREAS

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ABSTRACT

The main characteristics of both GPS (UHF) and Loran-C (LF) navigation systems are reviewed, with emphasis on vehicular navigation applications. The effect of the GPS line-of-sight requirement and that of Loran-C signal interference and attenuation in urban and mountainous areas are discussed. Unaided GPS and Loran-C signal availability statistics sufficient for 2-D positioning with HDOP < 5 are presented using GPS and Loran-C signal statistics obtained from tests conducted in Calgary and along roads of British Columbia. In Calgary, GPS availability is found to be better than Loran-C. This is attributed to a near complete satellite constellation and to the use of a fast signal acquisition GPS receiver. The use of integrated GPS/Loran-C improve GPS availability by only a few percents. In the mountains, the use of an integrated system increases availability to 95% as compared to 65% for GPS and 75% for multi-chain Loran-C.

INTRODUCTION

The objective of this paper is to assess and intercompare the performance of (i) GPS, (ii) Loran-C and (iii) integrated GPS/Loran-C for vehicular navigation with emphasis on the urban case. Availability of these systems along roads in mountainous areas of B.C. was investigated in [3, 71 and sample results for a 230~km road segment are presented in Table 1. In this case, the use of an integrated GPS/multi-chain Loran-C system resulted in a 94% availability, a significant improvement over any other configuration.

Table 1: Availability of Loran-C, GPS and GPS/Loran-C Between Osoyoos and Trail, B.C.(% of distance, HDOP ≤ 5)

GPS	61
Loran-C (Multi Chain)	77
Loran-C (Single Chain)	65
GPS/Loran-C Multi-Chain)	94
GPS/Loran-C (Single-Chain)	85

The major limitation of any RF navigation system is signal availability. Signal attenuation or masking occurs due to natural and man-made effects. In the case of GPS, the line-of-sight requirement limits signal availability in the mountains and urban areas. The over-the-horizon Loran-C signals are also attenuated by rugged topography and man-made obstructions. Loran-C phase distortion caused by rugged topography is severe and can result in absolute position errors of several hundred metres in mountainous areas [4]. This effect is permanent however and can he calibrated along the roads of interest with an accuracy of 50 to 100 m using a mobile DGPS system [6]. The 2drms accuracy of calibrated Loran-C can therefore increase to 100 m, depending on geometry. This accuracy level is similar to that of single point GPS under Selective Availability. The relevant characteristics of GPS and Loran-C are summarized in Table 2.

Table 2: **Major GPS and Loran-C Characteristics for Vehicular Navigation**

GPS (UHF, 1.5 GHz)

- Lime-of-sight propagation
- Short tropospheric path
- Affected by the ionosphere
- Not significantly affected by ground conductivity or atmospheric and man-made noise
- Signals blocked by topography and structures
- High measurement resolution (≤ 1 m)
- Absolute accuracy: 100 m under Selective Availability

Loran-C (LF, 100 KHz)

- Propagation along earths surface
- Line-of-sight not required
- Effects of refractivity (Primary Factor), ground conductivity (Secondary + Additional Secondary Factors), topography and atmospheric or man-made noise are significant
- Lower measurement resolution (10 - 30 m)
- Poor geometry in many areas
- Absolute accuracy: ≤ 500 m nominal
- 100 m calibrated (for permanent distortion effects)

In 1991, when the North Central U.S. Loran-C (NOCUS) Chain which provides good Loran-C coverage in the Calgary area became operational, a comparative analysis of Loran-C and GPS availability using a 6-channel GPS receiver showed the Loran-C availability to be superior [2]. With the GPS constellation near completion and faster signal acquision GPS receivers now available, it was decided to repeat the test.

EQUIPMENT SELECTION AND FIELD TESTS

The GPS measurements were conducted with two receiver types, namely a lo-channel NovAtel GPSCard™ [l] and a 6-channel commercial receiver. Many problems occured with the slower acquisition 6-channel unit during the tests and only results with the GPSCard™ will be reported herein. Results with a best 6-satellite constellation will however be compared with the all-in-view results to assess the impact of an all-in-view receiver. A multi-chain Jet 7201 digital Loran-C receiver was used. The performance of this receiver was previously analysed [7]. Reliable Loran-C signals from all four NOCUS chain transmitters and from the M and Y transmitters of the Canadian West Coast (CWC) chain are available in Calgary, as shown in Figure 1. The Loran-C data was reduced using the hyperbolic mode in which case a minimum of three transmitters is required. When more than two Time Differences (TDs) were available, a least-squares algorithm was used to obtain a unique solution. The Loran-C HDOP (Horizontal Dilution Of Precision) based on NOCUS is 1.7 in the Calgary area; the addition of the M-Y TD from the CWC chain results in a HDOP of 1.2. These two HDOP values are considered very good for Loran-C positioning. The on-board Loran-C and GPS receivers were time-synchronized using LORCAL[2], a system developed previously at The University of Calgary for Loran-C calibration [4, 6, 71. The GPS and Loran-C measurements were recorded every second.

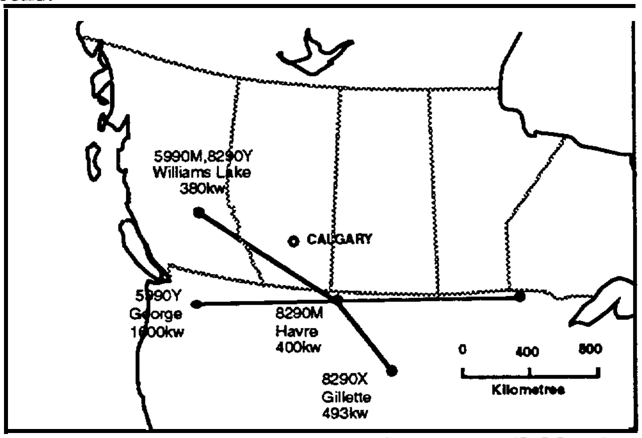

Figure 1: Loran-C Transmitters Available in Calgary Area

The test was conducted in Calgary during two periods on June 3,1993, namely between 0000 and 0130 (Test #l) and between 0630 and 0830 (Test #2), local time. The 60-km trajectory used is shown in Figure 2. Three road segments represent typical potential problems, namely (i) the presence of Power Line Carriers (PLC) which can interfere with Loran-C, (ii) the downtown core with buildings up to 50 stories where both Loran-C and GPS are likely to be affected, and (iii) tree-lined streets in a residential area where GPS signals may be affected.

The test #l period corresponds to the highest level of atmospheric noise expected in the 90 - 110 kHz Loran-C band. The test # 2 period coincides with the morning traffic rush which could result in man-made noise in the same band; atmospheric noise is also still relatively high during that period of the day. Since atmospheric noise is highest during Summer [8], the Loran-C results, in term of Signal-to-Noise Ratios (SNR), are likely to correspond to the worst case. During test #l, the number of satellites above an elevation of 5” varied between 7 and 9. During test #2, 6 to 10 satellites were available, with 7 or more satellites available over 85% of the time. The elevation and azimuth of the satellites available during test#2 are shown in Figure 3. The corresponding theoretical PDOP during either run was always <3, and the HDOP with the height fixed <2.

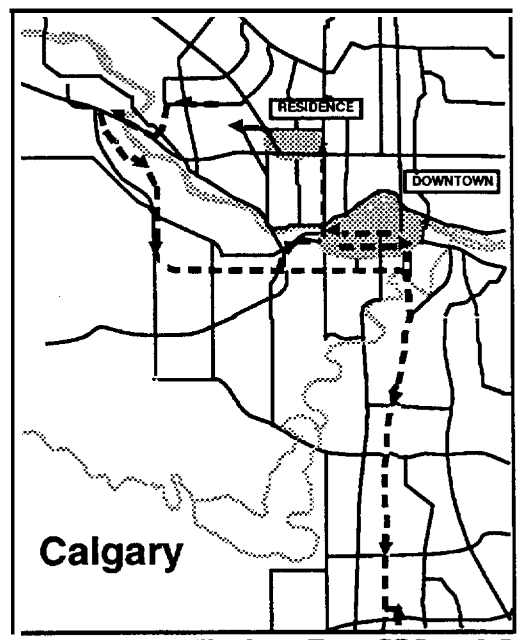

Figure 2: Trajectory Used to Test GPS and Loran-C

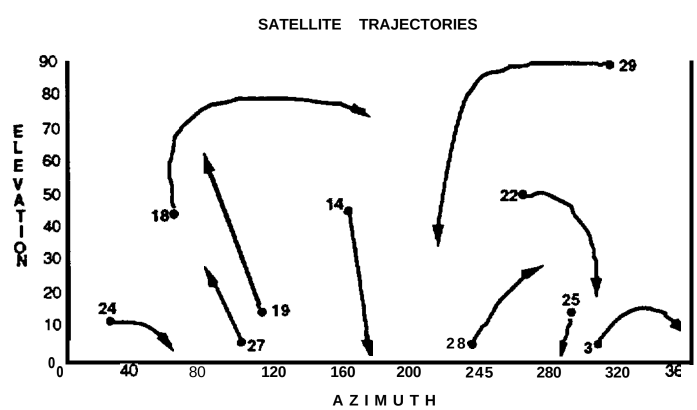

Figure 3: Satellite Elevations and Azimuths, Calgary, June 3, 1993, 0630 - 0830

ANALYSIS OF RESULTS

GPS: In most urban areas, as in this case, height variations do not generally exceed 100 m and the height component can be held fixed to an average value. Alternatively, a precise height could be extracted from an on-board database. Assuming the height known increases the degree of freedom by 1 and improves the HDOP. GPS availability is therefore defined herein as the case when the satellites actually available result in a HDOP ≤ 5 with the height fixed. The GPS HDOPs actually obtained during the two tests with the lo-channel GPSCard™ are shown in Figures 4 and 5, respectively. Occasional outages occur due to signal shading by buildings, mostly in the downtown area, as shown in the figures.

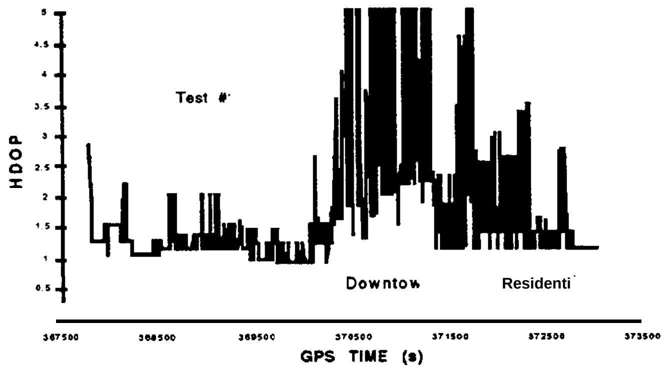

Figure 4: GPS HDOP (Height Fixed) Observed, June 3, 1993, 0000-0130

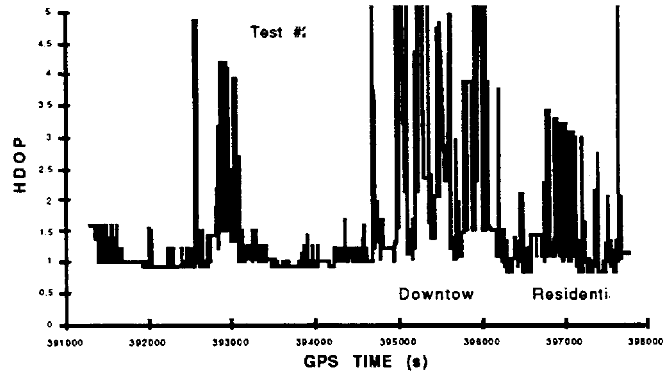

Figure 5:GPS HDOP (Height Fixed) Observed, June 3, 1993, 0630-0830

The percentage of distance for which GPS was available for various **segments** of the trajectory defined earlier are given in Table 2 using all satellites observed and using the satellites which would have been available with a 6-channel receiver. In the latter case, it is naturally assumed that the receiver would have attempted to track the 6 satellites which would theoretically have resulted in the best geometry, i.e., minimum HDOP. The difference between the 10 and 6-channel cases is only of the order of 2%. The light forestry canopy present in the residential area does not seem to have any significant effect on signal availability. GPS availability is significantly higher than during the 1991 test, yet the trajectory is similar. This is attributed to a more complete constellation and the use of a much faster signal reacquisition technology.

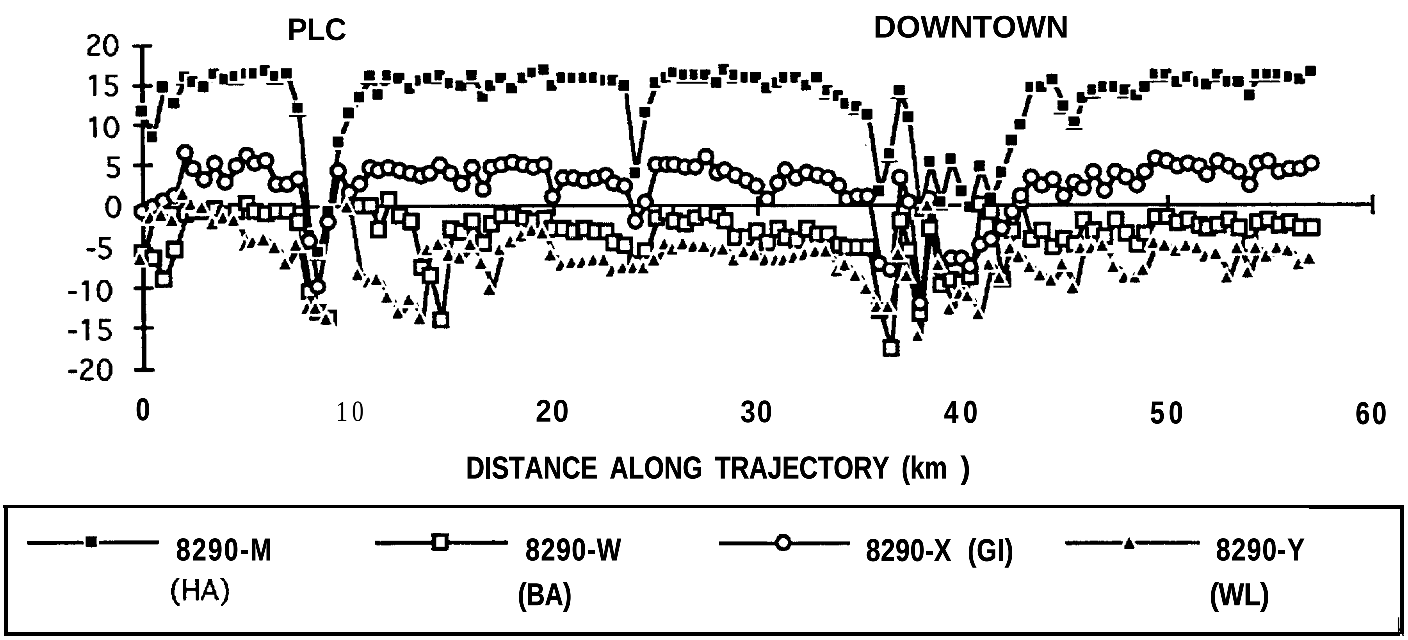

Figure 6: Measured SNR on NOCUS (0000-0130)

Table 2: GPS Availability Statistics (%)

Trajectory	10-Channel Receiver	Best 6-satellites
	Test #l (0000-0130)	
Entire Traj.	89	88
Downtown	62	60
Residential	99	99
	Test #2 (0630-0830)	
Entire Traj .	93	92
Downtown	77	75
Residential	99	97

LORAN-C: The SNR values measured on NOCUS during test #l are shown in Figure 6. The SNR measured during test#2 is 5 to 10 dB higher due to the stronger effect of the atmospheric noise. Significant data gaps occur along a PLC (Sarcee Trail) and in the downtown core. The percentages of distance for which Loran-C was available for the three segments of the trajectory defined earlier are given in Table 3. A comparison of Table 2 and 3 reveals that, in the downtown core, GPS availability is superior to Loran-C. For the entire trajectory, GPS availability is also superior, due to downtown results and the effect of the PLC outside the downtown core.

The differences between the Loran-C TDs measured on NOCUS and the corresponding DGPS-derived TDs are fairly constant and range from 3 to 4.5 ns. They are non-zero due to the combined effect of the Primary, Secondary and Additional Secondary Phase Factors. The differences are however practically constant in time and can be calibrated to increase the absolute accuracy of Loran-C to about l00m, the same as GPS in single point mode. See [6] for details. A comparison of DGPS and calibrated Loran-C positions show an agreement better than 100m.

Table 3: Loran-C Availability Statistics (%)

Trajectory	NOCUS Only	NOCUS + CWC
	Test #1 (0000-0130)	
Entire Traj.	66	73
Downtown	21	26
Residential	83	98
	Test #2 (0630-0830)	
Entire Traj .	56	76
Downtown	14	29
Residential	98	99

INTEGRATED GPS/LORAN-C: The GPS and Loran-C data collected during test#l was combined using a technique previously used [5] to generate the results shown in Table 1 [7]. A gain of about 3% for the entire trajectory and 5% for the downtown segment was achieved, as compared to the use of GPS in stand alone mode.

CONCLUSIONS

From the limited test results presented here, it appears that GPS is now better than Loran-C in term of signal availability in a urban area The use of fast t-e-acquisition receiver technology is a significant factor, especially in areas of high buildings and forestry canopy. The use of an integrated GPS/Loran-C results only in an availability increase of a few percent. A more extensive study is however required to confirm these findings and ascertain the availability percentages presented herein.

ACKNOWLEDGEMENT

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