PERFORMANCE EVALUATION OF REAL-TIME KINEMATIC GPS AT ARCTIC LATITUDES

Alessio Salerno\textsuperscript{1}  
Canadian Space Agency  
Saint-Hubert, QC, Canada

Tom Lamarche  
Canadian Space Agency  
Saint-Hubert, QC, Canada

Erick Dupuis  
Canadian Space Agency  
Saint-Hubert, QC, Canada

ABSTRACT

A real-time kinematic (RTK) global positioning system (GPS) has been identified for potentially being used as a ground-truth sensor for testing robotic rovers for planetary exploration. A series of environmental tests needs to be performed in order to validate the performance of the sensor at hand before being used as a ground-truth system. This paper focuses on the performance evaluation of the RTK GPS at Axel Heiberg Island Canadian Space Agency's Analogue Research Network (CARN) site. This is one of the officially recognized terrestrial analogues, that is places on Earth that approximate the geological, environmental and putative biological conditions on Mars and other planetary bodies (Hipkin et al.). The challenge lies in the use of the equipment at Arctic latitudes. The results show that the system performed according to specifications even in this challenging environment.

Keywords: Real-Time Kinematic GPS, Precision, Centimeter-Accuracy, Ground-Truth, Planetary Rovers.

INTRODUCTION

Many works have been focused in the past on the performance evaluation of standard global positioning systems (GPS). To cite a few: (Serr et al., 2006) (Mancebo and Chamberlain, 2000), (Rodriguez-Pérez et al., 2006), (Karsky et al., 2000) and (McCullough, 2002).

Some GPS testing has been performed at Arctic latitudes, e.g. (McEwen et al., 2005). However, there is limited information on the performance of real-time kinematic (RTK) GPS at Arctic latitudes.

\textsuperscript{1} Address all the correspondence to: alessio.salerno@asc-csa.gc.ca

Many challenges are faced when using GPS at high latitudes. In these conditions satellite constellation changes drastically because of the inclination of the satellite orbits; there is no direct pass of GPS satellites overhead when approaching the North Pole. In this environment all satellites are located closer to the horizon. At very high latitudes only low-elevation angles guarantee an increase of satellite visibility. This results in multipath errors and reduced geometry (Cannon et al., 2003).

This paper aims at assessing the relative (real-time kinematic) performance of a radio-modem-based RTK GPS system capable of 1Hz update frequency. Other differential GPS implementations, such as beacon-based, GSM/GRSM-based are disregarded because of their poor accuracy (~1m) (Magellan Navigation Inc., 2007b). Performance is assessed at the Canadian Space Agency’s Analogue Research Network (CARN) site in Axel Heiberg Island. Terrestrial analogues are places on Earth that approximate the geological, environmental and putative biological conditions on Mars and other planetary bodies, either at the present-day or sometime in the past (Hipkin et al., 2007). This analysis is of crucial importance for drawing conclusions on the accuracy and precision of this sensor, which will be deployed as a ground-truth system for testing robotic rovers for planetary exploration.

An experimental procedure consisting in setting up a grid at the CARN site is adopted. Three metrics are used to assess the performance of the sensor: ellipsoidal distance (ED) among the points of the grid, precision and accuracy.

The RTK GPS used is a professional one, namely the Promark3RTK from Magellan Navigation (Magellan Navigation Inc., 2007b). The sensor is a single frequency RTK
GPS. The manufacturer claims centimeter horizontal accuracy comparable to that of dual frequency GPS. This is achieved using the Blade™ technology, which has been embedded in the sensor. This technology relies on the space-based augmentation system (SBAS) (Magellan Navigation Inc., 2007d). Because SBAS relies on geostationary space vehicles (SV), it is crucial to test the potential performance decay of the sensor at high latitudes, where lack of coverage might become an issue.

NOMENCLATURE

CARN  Canadian Space Agency's Analogue Research Network  
ED    Ellipsoidal Distance  
MET   Mars Emulation Terrain  
RTK   Real Time Kinematic  
SV    Space Vehicle  
SBAS  Space-Based Augmentation System  
WGS84 World Geodetic System, 1984

EXPERIMENTAL PROCEDURE

RTK is a type of differential GPS where signal corrections are communicated in real time from a stationary base receiver to one or more remote moving receivers. Atmospheric delay and orbital errors along with other variables in GPS geometry are compensated. For this reason RTK GPS increases positioning accuracy.

Before departing for the mission at CARN site, the unit testing of the sensor was performed (Salerno and Dupuis, 2008a). Furthermore, the prediction of the GPS satellite constellation geometry during the days of testing at CARN site, was assessed using dedicated software (Magellan Navigation Inc., 2007c) based on the latest available GPS satellite almanacs (Magellan Navigation, 2007f). The adopted testing procedure at CARN site (Salerno and Dupuis, 2008c) was first tested at standard latitudes, namely at the Mars Emulation Terrain (MET) of the Canadian Space Agency (Salerno and Dupuis, 2008b). The recorded mean and standard deviation of the accuracy are 61mm and 56mm, respectively.

Experiments were performed on July 26 and 29, 2008 at Expedition Fiord on Axel Heiberg Island, Nunavut, Canada. A 12m x12m grid, made of spikes, was set-up using the 3-4-5 rule with a rope. The small overall size of the grid does not require any height factor correction when computing the ellipsoidal distance. The actual grid is depicted in Figure 2. The relative position between the spikes was affected by a +/-20mm tolerance introduced by the manual set-up of the grid. A schematic of the grid is reported in Figure 1. Spikes are visited by the RTK GPS rover. Each time the rover visits the spike, a reading is recorded. Five readings were taken for each point of the grid. Each reading featured a time span of 15 seconds. Points were logged in RTK mode.

The hardware set-up used for the survey is reported in Figure 3. A 4-ft long range pole was used for the RTK GPS rover, while a standard surveying tripod was used for the RTK GPS base. The rover was initialized using the kinematic bar procedure.

Performance was evaluated for different distances between the RTK GPS base and grid: 0km, 0.5km and 1km. The 0km test was performed on July 26, 2008. The base was located onto the origin of the grid, i.e. point A.

The 0.5km test was conducted on July 29, 2008. Test lasted approximately two hours (from 12-noon to 2pm CDT). The base was plumbed on a point at distance of 595m from the grid. The number of SVs tracked during the survey oscillated between nine and ten. All the RTK solutions were fixed, i.e. featured centimeter-accuracy.

FIGURE 1 – GRID SCHEMATIC

The 1km test was conducted on July 29, 2008. Test lasted approximately two hours (from 5pm to 7pm CDT). The base was plumbed on a point at a distance of 1150m from the grid. The number of SVs tracked during the survey oscillated between 11 and 12. The fifth readings of points N and P are associated to conditions where the real-time kinematic fixed signal was lost. During the test the RTK signal was lost three times. To regain the signal a re-initialization of the rover was performed three times. During the re-initialization the rover was lifted 4 feet above the ground in order to improve the communication with the base. As shown in the sequel, this performance decay is not caused by the Arctic latitudes but rather by the radio modems.
RESULTS AND DISCUSSION

For each of the points/spikes and each of the base-grid distances we compared the ED on the World Geodetic System (WGS) 1984 from the origin of the grid using the inverse computation algorithm (National Geodetic Survey, 2008).

Accuracy

The accuracy is computed as the absolute value of the difference between the ED and the distance measured using the grid. The collected data are analyzed for each point upon varying the base-grid distance. The data are compared using box plots, see Figs. 4-14.
FIGURE 8 ACCURACY: A-F, A-G AND A-H

FIGURE 9 ACCURACY: A-I, A-J AND A-K

FIGURE 10 ACCURACY: A-L, A-M AND A-N

FIGURE 11 ACCURACY: A-O, A-P AND A-Q
The tops and bottoms of each of the box plots are the 25th and 75th percentile; the red line is the median while outliers are represented with the + sign. Outliers are observations that are more than 1.5 times the interquartile.

The width of the notches reported on the box plots is computed so that those plots whose notches do not overlap have different medians at the 5% significance level, assuming a normal distribution. Comparisons of medians are reasonably robust also for other distributions. These comparisons can be regarded as visual hypothesis tests.

The results of the visual hypothesis tests applied to Figs. 4-14 are reported in Table 1. For example, with reference to the accuracy associated to the measurement of the ED between spike B and the origin, we can infer, from the result of Table 1, that:

- Hypothesis test is false for the medians associated to 0km and 0.5km base-grid distances; the medians of the accuracies are different at a 5% significance level.
- Hypothesis test is true for the medians associated to 0km and 1km base-grid distances; the medians of the accuracies are equal at a 5% significance level.
- Hypothesis test is false for the medians associated to 0.5km and 1km base-grid distances; the medians of the accuracies are different at a 5% significance level.

In Fig. 15 we report the accuracy associated to the measurements of all the points of the grid for the three different base-grid distances.

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Are medians associated to the following base-grid distances equal?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0km &amp; 0.5km</td>
</tr>
<tr>
<td>A-B</td>
<td>No</td>
</tr>
<tr>
<td>A-C</td>
<td>No</td>
</tr>
<tr>
<td>A-D</td>
<td>Yes</td>
</tr>
<tr>
<td>A-E</td>
<td>Yes</td>
</tr>
<tr>
<td>A-F</td>
<td>Yes</td>
</tr>
<tr>
<td>A-G</td>
<td>No</td>
</tr>
<tr>
<td>A-H</td>
<td>No</td>
</tr>
<tr>
<td>A-I</td>
<td>Yes</td>
</tr>
<tr>
<td>A-J</td>
<td>No</td>
</tr>
<tr>
<td>A-K</td>
<td>No</td>
</tr>
<tr>
<td>A-L</td>
<td>No</td>
</tr>
<tr>
<td>A-M</td>
<td>Yes</td>
</tr>
<tr>
<td>A-N</td>
<td>Yes</td>
</tr>
<tr>
<td>A-O</td>
<td>No</td>
</tr>
<tr>
<td>A-P</td>
<td>Yes</td>
</tr>
<tr>
<td>A-Q</td>
<td>No</td>
</tr>
<tr>
<td>A-R</td>
<td>Yes</td>
</tr>
<tr>
<td>A-S</td>
<td>No</td>
</tr>
<tr>
<td>A-T</td>
<td>No</td>
</tr>
</tbody>
</table>

### TABLE 1 COMPARISON OF THE ACCURACY OF MEASUREMENTS

Assuming that outliers are observations that are more than 1.5 times the interquartile, we have that the median of the accuracy associated to the 0km test is equal to that of the 0.5km test and that of the 1km test, both at significance of 5%. However, the median associated to the 0.5km test or to the 1km test is not equal to the 0km test.

The mean and standard deviation values in terms of accuracy associated to all measurements are reported in Table 2. As we can see, the accuracy is the same no matter what base-rover distance is used. However, only the standard deviations associated to the 0km and the 0.5km tests are almost equal. The
standard deviation associated to the 1km test is twice the standard deviations of the other tests.

During the 1km experiment
- the fifth reading of Point J,
- 75% of the reading of point N,
- all the readings of point O,
- the last two readings of point R and
- the fifth reading of point Q,

the RTK signal switched from fixed (guarantees centimeter accuracy) to float (guarantees two-decimeter accuracy). This signal switch is motivated by the choice of base-grid distance of 1150m which is greater than the 1000m-radio-modem-range specification. Figs. 10 and 11 confirm the RTK GPS signal switch. This is confirmed also by the hypothesis tests on the medians. However, the RTK GPS at hand outputs a conservative output since the Figs. 9, 11 and 12 features accuracy smaller than 20cm.

The figures of accuracy reported in Table 2 are conservative since they also include the contribution of +/-20mm associated to the manual set-up of the grid. These figures match the accuracy recorded at MET, thus confirming the absence of any significant performance decay.

Precision
FIGURE 20 PRECISION: A-F, A-G AND A-H


FIGURE 23 PRECISION: A-O, A-P AN A-Q
In Fig. 27, we report the precision of the measurements associated to all the points of the grid for the three different base-grid distances. From Fig. 27, assuming that outliers are observations that are more than 1.5 times the interquartile, we have that the median of the precision associated to the 0.5km test is equal to that of the 1km test at a significance of 5%. However, the median associated to the 0.5km test or to the 1km test is not equal to the 0km test.

The mean and standard deviation values in terms of precision associated to all measurements are reported in Table 4. As we can see, the precision almost doubles when going from a 0km base-rover distance to a 0.5km one. It almost triplicates when going from 0.5km to 1km base-rover distance. As far as standard deviation is concerned, it doubles when going from a 0km to 0.5km base-rover distance. However, the standard deviation associated to the 0.5km base-rover distance is almost ten times the standard deviation associated to the 1km base-rover distance.

<table>
<thead>
<tr>
<th>Precision</th>
<th>Are medians associated to the following base-grid distances equal?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0km &amp; 0.5km</td>
</tr>
<tr>
<td>A-B</td>
<td>Yes</td>
</tr>
<tr>
<td>A-C</td>
<td>No</td>
</tr>
<tr>
<td>A-D</td>
<td>Yes</td>
</tr>
<tr>
<td>A-E</td>
<td>Yes</td>
</tr>
<tr>
<td>A-F</td>
<td>No</td>
</tr>
<tr>
<td>A-G</td>
<td>Yes</td>
</tr>
<tr>
<td>A-H</td>
<td>No</td>
</tr>
<tr>
<td>A-I</td>
<td>No</td>
</tr>
<tr>
<td>A-J</td>
<td>Yes</td>
</tr>
<tr>
<td>A-K</td>
<td>Yes</td>
</tr>
<tr>
<td>A-L</td>
<td>Yes</td>
</tr>
<tr>
<td>A-M</td>
<td>Yes</td>
</tr>
<tr>
<td>A-N</td>
<td>No</td>
</tr>
<tr>
<td>A-O</td>
<td>No</td>
</tr>
<tr>
<td>A-P</td>
<td>No</td>
</tr>
<tr>
<td>A-Q</td>
<td>No</td>
</tr>
<tr>
<td>A-R</td>
<td>Yes</td>
</tr>
<tr>
<td>A-S</td>
<td>Yes</td>
</tr>
<tr>
<td>A-T</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**TABLE 3 COMPARISON OF THE PRECISION OF THE MEASUREMENTS**

**FIGURE 27 PRECISION (ALL POINTS)**

**FIGURE 24 PRECISION (A-R)**

**FIGURE 25 PRECISION (A-S)**

**FIGURE 26 PRECISION (A-T)**
DISTANCE | DEVIATION [MM]
---|---
0KM | 2
0.5KM | 4
1KM | 11

**TABLE 4 PRECISION**

Ellipsoidal Distance

The shape and relative location of the box plots obtained for the ED is identical to that of Figs. 4-14 except for point P, whose box plot we report in Fig. 28. Therefore, as far as ED is concerned, the results on the comparison among the different base-grid distances are identical to those reported in Table 1 except for point P.

**FIGURE 28 ELLIPSOIDAL DISTANCE (A-P)**

**CONCLUSIONS**

Methodology, experimental results and discussion on the performance evaluation of RTK GPS at Arctic latitudes have been presented.

We have shown that the RTK GPS centimeter-accuracy is preserved even upon varying the base location up to the maximum range of the radio modems. The sensor performed with centimeter precision as well. The performance decay that usually is experienced with standalone GPS at high latitudes does not apply to the RTK GPS at hand. This might be due to the unique features of the RTK technology.

Future works will focus on the use of the sensor as a ground truth sensor for robotic rovers for planetary exploration.

**REFERENCES**


