Does a consumer GPS receiver achieve submeter accuracy under forest canopy?*

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Abstract
It is known that high-end GPS receivers work better under forest canopy than consumer GPS receivers. However, higher costs of them are a major obstacle for forest owners and managers to utilize them for forest management. For this reason, we should make more use of consumer GPS receivers by overcoming difficulties in getting better positional accuracy under forest canopy. The objectives of this study are to determine positional errors of a consumer GPS receiver under forest canopy and to clarify the conditions and requirements to achieve submeter accuracy using a consumer GPS receiver. Therefore, in this study, we conducted field experiments of GPS positioning with different methods of data correction (code-phase and carrier-phase DGPS) and periods of data collection (2 to 300 minutes). The GPS receiver used in this study was Earthmate USB GPS (DeLorme) that is capable of receiving L1 carrier-phase data and generating Rinex files. These files were differentially corrected by using GPS PostPro 2.0 (DeLorme), which is capable to output only float solutions for carrier-phase data. The results showed that positional errors were unstable and unpredictable when code-phase DGPS was used. In addition, there was no relationship between positional errors and periods of data collection. On the other hand, it was found that positional errors were smaller with increasing periods of data collection when carrier-phase DGPS was used, and that sub-meter accuracy was achieved under forest canopy when the period of data collection was 300 minutes. We also used three different base stations for data correction with different distances from the remote station (2 to 234 km). As a result, relatively large positional errors were sometimes produced for carrier-phase DGPS when the distance between the remote station and base station was 234 km.

1. INTRODUCTION

It is known that forest canopy adversely affects positional accuracy of GPS positioning due to signal attenuation, and this has been a major obstacle of GPS utilization for forest management. Therefore, many studies have been conducted to determine the performance of GPS positional accuracy under forest canopy. Martin et al. (2001) evaluated DGPS positional accuracy and precision on Irish forest roads with typical peripheral canopies and discussed the relationship between position dilution of precision (PDOP) and the percentage of open sky. This study also showed that both DGPS accuracy and precision improved with decreasing peripheral obstruction. Næsset (1999) showed that the accuracy of GPS positioning was significantly higher with the 12-channel GPS receiver than with the 6-channel GPS receiver and was significantly higher with the combined use of the C/A code and carrier phase than with the use of

the C/A code only. Kobayashi et al. (2001) evaluated five GPS receivers’ performance by comparing the positional accuracy of the autonomous GPS, real-time DGPS, and carrier phase GPS. Results indicated that the autonomous GPS and real-time DGPS produced positional errors of 15.4–48.6m and 2.7–21.7 m, respectively, which were based on the condition that SA was on. Sawaguchi et al. (2001) discussed the effect of stand conditions on positioning precision with real-time DGPS and found factors that affected positional precision by using multiple regression analysis. Mori and Takeda (2000) showed the effects of SA removal on positional accuracy of the DGPS. In most of these studies, high-end GPS receivers that work well even under forest canopy were used, but they often cost too much for forest owners and managers in Japan, who are struggling with the difficult market environment. In fact, high-end ones often cost more than 3,000 USD while consumer GPS receivers cost only 100-500 USD. For this reason, we should make more use of consumer GPS receivers by overcoming difficulties in getting better positional accuracy under forest canopy. The objectives of this study are to determine positional errors of a consumer GPS receiver under forest canopy and to clarify the requirements to achieve submeter accuracy using a consumer GPS receiver. Therefore, in this study, we conducted field experiments of GPS positioning with different methods of differential correction and periods of data collection. We also used three different base stations for differential correction with different distances from the remote station.

2. MATERIALS AND METHODS

2.1 GPS and software

The GPS receiver used in this study was Earthmate USB GPS (DeLorme) (Figure 1) that is capable of receiving L1 carrier-phase data and generating Rinex files for differential correction. Moreover, this GPS receiver is characterized by its small size (1 7/8” wide by 2 3/32” long), fast signal acquisition (in under 45 seconds), USB connection without external batteries, WAAS capability, 12 channels, NMEA compliance and low-power consumption. The GPS data collected with this GPS receivers were differentially corrected by using GPS PostPro 2.0 (DeLorme), which is capable to output only float solutions for carrier-phase data. This software provides an array of tools for working with Rinex files, single carrier phase processing for static baselines, code (DGPS) processing for dynamic baselines, automatic correction against CORS reference stations, or against a second stationary Earthmate USB GPS, an intuitive wizard interface through the post processing steps, satellite prediction tools for data collection mission planning and a detailed report of the post processed results. This software calculates the coordinates as float solutions for carrier-phase DGPS. The price of Earthmate USB GPS including GPS PostPro 2.0 is approximately 300 USD.
2.2 Field experiments

We conducted field experiments inside the forest of the Kamigamo Experimental Station, Field Science Education and Research Center, Kyoto University on February 23 to 25, 2006. Earthmate USB GPS was set up at three points, that is, K2, A5 and A8, inside the forest. K2 was located in a forest glade on the top of the hill with good visibility of GPS satellites. A5 was at the side of a forest road on the top of the hill, and was surrounded by natural forest stands consisting of Japanese cypress (Chamaecyparis obtusa) and broad-leaved species with a thick shrub layer. A8 was at the side of a forest road on the hillside under closed canopy of Japanese cypress (Chamaecyparis obtusa). Figure 2 shows fisheye photos taken at these points.

At each point, GPS measurements were conducted for 300 minutes as shown in Table 1. We started each GPS measurement four minutes earlier on the next day because the same constellation of GPS satellites appears four minutes earlier day by day. Figure 3 shows the number of visible GPS satellites during the field experiments. In this study, horizontal positional errors were calculated and compared in terms of accuracy, which refers to the closeness of the
sample mean to the true value (Leick 1995) and was calculated according to Yoshimura and Hasegawa (2003).

Table 1. Schedule of the field experiments.

<table>
<thead>
<tr>
<th>Date</th>
<th>Point</th>
<th>Antenna height (m)</th>
<th>Starting time (JST)</th>
<th>Ending time (JST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 23, 2006</td>
<td>K2</td>
<td>1.69</td>
<td>10:24:00</td>
<td>15:23:59</td>
</tr>
<tr>
<td>February 24, 2006</td>
<td>A5</td>
<td>1.41</td>
<td>10:20:00</td>
<td>15:19:59</td>
</tr>
<tr>
<td>February 25, 2006</td>
<td>A8</td>
<td>1.41</td>
<td>10:16:00</td>
<td>15:15:59</td>
</tr>
</tbody>
</table>

JST, Japan Standard Time (UTC+9 hours).

Figure 3. Number of visible GPS satellites during the field experiments.

2.3 Data processing

The GPS data collected on each day were differentially corrected using the data of the first 2, 5, 10, 30, 60, 120 and 300 minutes with two methods of differential correction, that is, code-phase and carrier-phase DGPS to clarify the effects of methods of differential correction and periods of data collection on positional accuracy. In addition, we used three different base stations for differential correction with approximate distances of 2, 15 and 234 km from the remote station to clarify the effects of distance between the remote and base stations on positional accuracy.

3. RESULTS AND DISCUSSION

Tables 2 and 3 show positional errors calculated for code-phase and carrier-phase DGPS, respectively. The base station used for this calculation was the one that was at a distance of 2 km from the remote station. As shown in Table 2, longer elapsed time of measurements did not always produce better positional errors. Instead, it can be seen that positional errors became
worse for 60 – 120 minutes of elapsed time at K2 and A8 and for 5 – 10 minutes of elapsed time at A5. It should be also noted that positional errors at A5 were much larger than those at K2 and A8. Obviously, there were multipath errors in the data collected at A5. As a result, it was found that positional errors for code-phase DGPS were unstable especially under forest canopy due to possible effects of multipath. Table 3 shows that there was not a great difference in positional errors between code-phase and carrier-phase DGPS, but positional errors at A5 that were affected by multipath did improve steadily as elapsed time of measurements advanced. It should be also noted that submeter accuracy was achieved at all three points after 300 minutes of elapsed time of measurements.

Table 2. Positional errors for code-phase DGPS (m).

<table>
<thead>
<tr>
<th>Point</th>
<th>Elapsed time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>K2</td>
<td>3.22</td>
</tr>
<tr>
<td>A5</td>
<td>30.69</td>
</tr>
<tr>
<td>A8</td>
<td>1.57</td>
</tr>
</tbody>
</table>

Table 3. Positional errors for carrier-phase DGPS (m).

<table>
<thead>
<tr>
<th>Point</th>
<th>Elapsed time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>K2</td>
<td>1.40</td>
</tr>
<tr>
<td>A5</td>
<td>25.37</td>
</tr>
<tr>
<td>A8</td>
<td>3.99</td>
</tr>
</tbody>
</table>

Figures 4 and 5 show positional errors according to the distance between the remote station and base stations for code-phase and carrier-phase DGPS, respectively. As shown in Figure 4, there was not a great difference in positional errors according to the distance between the remote station and base stations for code-phase DGPS. On the other hand, there were relatively large positional errors for carrier-phase DGPS when the distance between the remote and base stations was 234 km (Figure 5). It should be noted that longer elapsed time of measurements such as 120 or 300 minutes may have eliminated such a distance effect. As a result, it is recommended to conduct GPS measurements for longer time when the base station is not closely located from the remote station.

4. CONCLUSIONS

In this study, submeter accuracy was achieved under forest canopy by using Earthmate USB GPS, but it was not done constantly. For one reason, consumer GPS receivers such as Earthmate USB GPS are influenced by multipath effects more easily than high-end GPS receivers that sometimes use multipath rejection technology. In fact, there were multipath errors seen in the data collected at A5, and positional errors for code-phase DGPS were unstable especially under forest canopy due to possible effects of multipath. On the other hand, carrier-phase DGPS with GPS PostPro 2.0 eliminated such negative effects, and submeter accuracy was achieved at all three points after 300 minutes of elapsed time of measurements. As for the
distance between the remote and base stations, it is recommended that GPS measurements should be conducted for longer time such as 120 or 300 minutes only when there are not available base stations closely located from the remote station. In conclusion, requirements to constantly achieve submeter accuracy under forest canopy are:

- To use Earthmate USB GPS and GPS PostPro 2.0
- To use carrier-phase DGPS for differential correction
- To conduct GPS measurements 300 minutes or more
- To use a base station up to 234 km from a remote station

Of course, GPS measurements for 300 minutes are not practical especially when there are many coordinates of points to be determined. Alternatively, to achieve positional accuracy up to 3 m, GPS measurements can be conducted for only 5 minutes, but a base station up to 15 km from a remote station must be used for carrier-phase DGPS.
Figure 4. Positional errors for carrier-phase DGPS according to the distance between the remote station and base stations at K2 (upper left), A5 (upper right) and A8 (lower left).

Figure 5. Positional errors for code-phase DGPS according to the distance between the remote station and base stations at K2 (upper left), A5 (upper right) and A8 (lower left).
5. ACKNOWLEDGEMENTS

The authors would like to thank Dr. Mitsuhiro Nose for his helpful assistance during the field experiments.

6. LITERATURE CITED


