Accuracy variation of dual-frequency GPS surveying under forest canopy by using an extendable GPS antenna pole

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ABSTRACT: It is well-known that forest canopy adversely affects GPS positional accuracy. There have been many studies to show the GPS positional errors based on observation data under forest canopy, but these studies did not propose proactive ways to improve the accuracy. Therefore, we introduced an extendable GPS antenna pole to GPS measurements under forest canopy. This antenna pole was made of carbon to reduce its weight and to enhance its portability in the forest environment. Field experiments were conducted at a survey point under forest canopy. We used dual-frequency GPS receivers for data collection while changing the GPS antenna height at 2, 5, 8 and 11m. In this study, we compared the GPS positional accuracy by the antenna height (2, 5, 8 and 11m), observation period (1,5, 10, 15, 30 and 60min) and type of solutions (L1 code, L1 float, L1 fix , L2 float and L2 fix solutions). The results for the L1 code solution clearly showed that the positional accuracy was enhanced by raising the GPS antenna to a higher position. As for the L1 and L2 float solutions, the positional accuracy of shorter periods (1, 5 and 10min) was improved by raising the antenna while that of longer periods (15, 30 and 60min) was not always improved. It was also found that the positional accuracy for the L1 and L2 fix solutions was not improved by raising the antenna, but the success rate of ambiguity resolution was more improved as the antenna was set higher under forest canopy.

1. INTRODUCTION

GPS is becoming increasingly a popular and common tool for forest management and utilization. However, it is well-known that forest canopy adversely affects GPS positional accuracy when it is used in the forest environment. There have been many studies to determine the GPS positional errors based on observation data under forest canopy (Hasegawa et al. 1998, Mori et al. 2000, Kobayashi 2002, Yoshimura and Hasegawa 2003), but these studies did not propose proactive ways for accuracy improvement. Some other studies aimed to make an estimation model of GPS positional accuracy under forest canopy (Næsset 1999, Næsset and Jonmeister 2002, Tachiki et al. 2004). It is clear that we can avoid adverse effects of forest canopy on GPS positional accuracy to raise a GPS antenna over forest canopy. Obviously, forest canopy is often too high to do that, but several studies showed that it was still effective for accuracy improvement to raise a GPS antenna to a position not higher than forest canopy. D'Eon (1996) showed that GPS positions obtained within 5min under mixed forest canopies were better at an antenna height of 4m than at an antenna height of 2m interms of PDOP (Position Dilution Of Precision). Gandaseca et al. (2001) indicated that GPS positional accuracy could be improved by changing the antenna height from 1.0m to 4.2m. Sawaguchi et al. also confirmed this by comparing the GPS positional accuracy with the antenna height of 1m and 7m. The results of these studies showed that it was one of the proactive methods for improving GPS positional accuracy to raise a GPS antenna as high as possible under forest canopy. In this study, GPS positional accuracy with different antenna heights was determined with a dual-frequency GPS receiver. There are few studies that showed the positional accuracy of a dual-frequency GPS receiver used under forest canopy (Næsset 2001, Hasegawa and Yoshimura 2003, Hasegawa and Yoshimura 2007), and none of them studied GPS positional accuracy with different antenna heights. This study also analyzed the effects of tree density around the GPS antenna set up at different heights on the positional accuracy.

MATERIALS AND METHODS

2.1 GPS antenna pole

The GPS antenna pole is made of carbon to reduce its weight to 4.2kg. The length of the antenna pole can be adjustable from 1 to 15m. As a result, it has good portability in the forest environment. However, strong wind often swung the GPS antenna pole because it was not supported by guylines.

2.2 GPS receiver

We used a dual-frequency GPS receiver (Leica SR530) for this study. This GPS receiver uses L1 and L2 frequency signals for measurements and gives sub-inch accuracy as long as there are no obstacles around the receiver.

2.3 Field experiments

Field experiments were conducted at a survey point under forest canopy in the

Kamigamo Experimental Station, Field Science Education and Research Center in Kyoto University. The survey point was surrounded by natural forest stands consisting of Japanese cypress (*Chamaecyparis obtusa*) and some broad-leaved trees. We conducted GPS measurements at heights of 2, 5, 8 and 11m by using the GPS antenna pole. At the same time, the GPS data was logged at a continuous operating reference station managed by Kyoto University. The settings of the GPS receivers used in this study are shown in Table 1. The schedule of the field experiments is shown in Table 2. The session numbers 1 to 4 were given to the sessions in order from morning to evening. As shown in this table, the one-hour GPS measurement was conducted for each session. The four GPS measurements of the same session number were conducted with four different antenna heights (2, 5, 8 and 11m) to mitigate the effects of the number of available GPS satellites varying over time.

Table 1. The settings of the GPS receivers used in this study

Type of GPS receiver	Mask	SNR mask (db)	Elevation mask (degree)	Logging interval (sec)
Leica SR530	20 (GDOP)	32	10	1
Trimble 4700 (Base Station)	25 (PDOP)	0	10	1

Table 2. Schedule of the field experiments (JST: Japan Standard Time or UTC+9h)

Date	Session no.	Starting time (JST)	Ending time (JST)	Antenna height (m)
March 6, 2008	1	10:28:00	11:28:00	8
	2	11:58:00	12:58:00	2
	3	13:28:00	14:28:00	11
	4	14:58:00	15:58:00	5
March 7, 2008	1	10:24:00	11:24:00	2
	2	11:54:00	12:54:00	5
	3	13:24:00	14:24:00	8
	4	14:54:00	15:54:00	11
March 10, 2008	1	10:12:00	11:12:00	5
	2	11:42:00	12:42:00	11
	3	13:12:00	14:12:00	2
	4	14:42:00	15:42:00	8
March 11, 2008	1	10:08:00	11:08:00	11
	2	11:38:00	12:38:00	8
	3	13:08:00	14:08:00	5
	4	14:38:00	15:38:00	2

The GPS data for each session was divided to make 1-, 5-, 10-, 15-, 30- and 60-minute portions. Thus, the numbers of the GPS data portions for 1-, 5-, 10-, 15-, 30- and 60-minute GPS measurements were 60, 12, 6, 4, 2 and 1, respectively. The number of available GPS satellites at an elevation mask of 10 degrees ranged from 7 to 11 during the field experiments. In addition, we started each GPS measurement four minutes earlier per day on the next session because the same distribution of GPS satellites appears four minutes earlier day by day.

2.4 Stand conditions

We measured the locations and heights of all the trees with their heights of 2m or more and within 10m from the survey point to calculate the tree density around the GPS antenna. It should be noted that the tree density around the GPS was calculated by considering the 10-degree elevation mask of the GPS receiver and the slope of the ground. As a result, the tree densities with the GPS antenna heights of 2, 5, 8 and 11m were 4427, 3057, 1879 and 618 trees/ha, respectively. Then, we took fisheye photographs at the four different antenna heights of the survey point using a digital camera (NIKON COOLPIX 4500) with a fisheye converter (NIKON FC-E8). Figure 1 visualizes the canopy conditions around the GPS antenna at the four different antenna heights of the survey point. This figure clearly shows the coverage of the tree stems and crowns over the GPS antenna became thinner when it was set up at a higher position.

Figure 1. Fisheye photographs at heights of 2, 5, 8 and 11m starting from the left

RESULTS AND DISCUSSION

The results for the L1 code solution clearly showed that the positional accuracy was improved by raising the GPS antenna higher (Figure 2). As for the L1 and L2 float solutions (Figures 3 and 5), the positional accuracy of shorter periods (1, 5 and 10min) was improved by raising the antenna while that of longer periods (15, 30 and 60min) was not always improved. It was also found that the positional accuracy for the L1 and L2 fix solutions was not improved by raising the antenna (Figures 4 and 6). It should be noted that as for the L1 and L2 fix solutions, the positional accuracy at the antenna height of 11m was worse than that at the antenna heights of 2, 5 and 8m. This was probably because the GPS antenna pole was swung by the wind especially when it was set up at the height of 11m or almost over the canopy although we did not observe the wind speed during the field experiments. The success rates of ambiguity resolution were more improved as the antenna was set up higher (Figures 7 and 8). As shown in these figures, we got the L1 and L2 fix solutions the most frequently when the GPS antenna was set up at the height of 11m, that is, almost over the forest canopy. On the other hand, we did not get the L1 fix solutions at all when the antenna height was 2m. In conclusion, the success rates of ambiguity resolution were affected by the tree conditions significantly, and would be the highest when the GPS antenna is over the forest canopy.

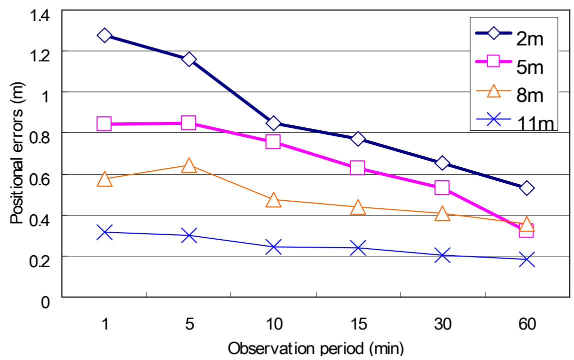

Figure 2. Positional errors by the observation period for L1 code solutions

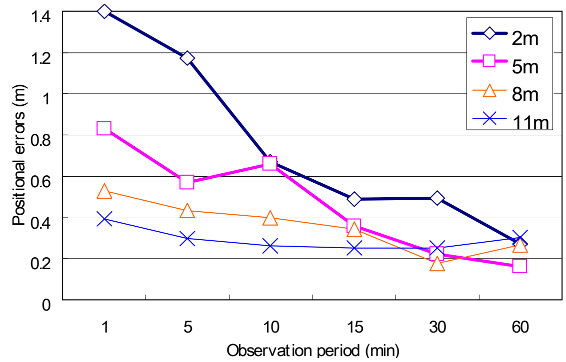

Figure 3. Positional errors by the observation period for L1 float solutions

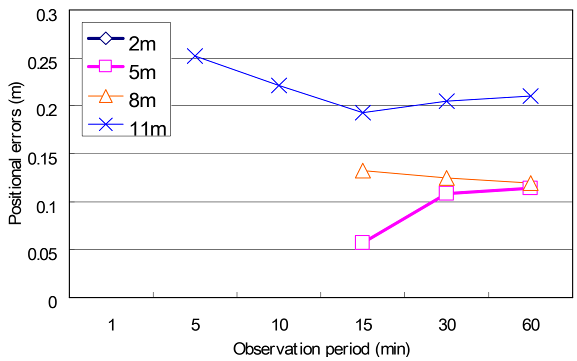

Figure 4. Positional errors by the observation period for L1 fix solutions

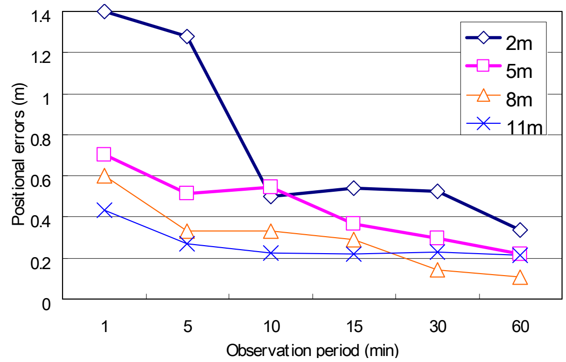

Figure 5. Positional errors by the observation period for L2 float solutions

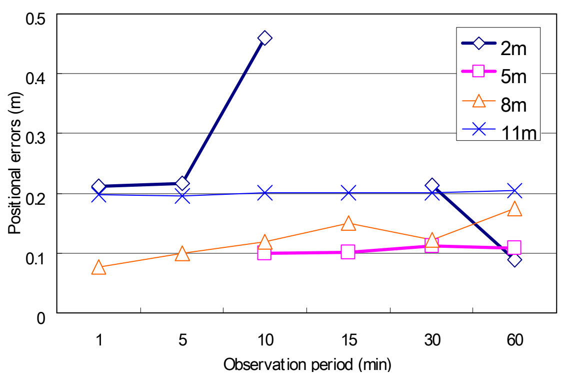

Figure 6. Positional errors by the observation period for L2 fix solutions

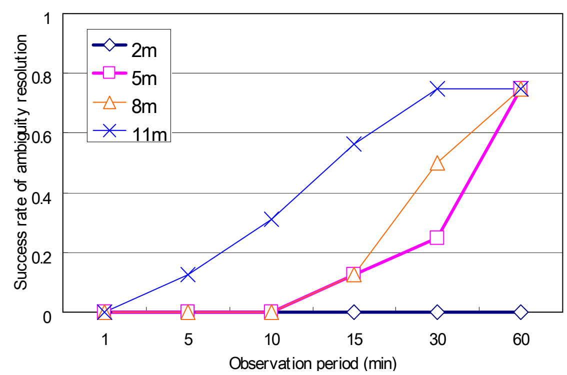

Figure 7. Success rate of ambiguity resolution for L1 by the observation period

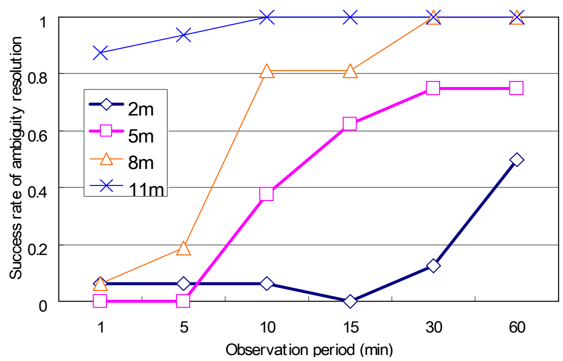

Figure 8. Success rate of ambiguity resolution for L2 by the observation period

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