Accuracy Assessment of a Post-processing Differential GPS Device: A Case Study in Kaman and Hacıtuğrul, Central Turkey

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ABSTRACT

The accuracy of a differential GPS (DGPS) device is preliminarily examined prior to using it for topographic survey in Kaman and Hacıtuğrul in central Turkey. Measurement duration is revealed to most dominantly affect the resultant position accuracy, and a certain minimum time is necessary for each measurement point to acquire the position accuracy needed for detailed field survey. This is not always clearly indicated by device manufacturers. Users should therefore be aware of the characteristics and capability of devices in advance of use in field survey.

Keywords: DGPS, accuracy assessment, field survey, measurement duration

INTRODUCTION

The use of GPS (Global Positioning System) is fundamental for measuring locations and shapes of archaeological sites and structures (*e.g.*, Fenwick 2004; Miyahara 2006). However, commercial GPS devices often do not correct for GPS signal errors, giving only limited accuracy (usually tens of meters), and so can be inappropriate for use in field surveys requiring higher accuracies. DGPS (Differential GPS) devices that are capable of applying corrections to the received signals have better accuracy, on the submeter scale. However, because the accuracies stated by the manufacturers of GPS devices are based on measurement testing under a limited range of conditions, they often do not reflect the accuracy during use in field surveys. It is therefore important to examine how a particular device works at any field site before using it for detailed measurements. Here we examine the accuracy characteristics of DGPS devices used at two field sites (Kaman and Hacıtuğrul in central Turkey), prior to using the devices for measurements in topographic surveys at the sites.

Although we tested only one type of DGPS device here due to financial concerns, our assessment is not limited to a specific product, and we aim to show the importance of assessing the functionality of any GPS device before using it for field survey.

METHOD

We used a portable DGPS device, MobileMapper Pro by Magellan Navigation Inc (Fig.1). This DGPS device is small (16.5×7.3×3 cm) and light (220 g), so can readily be carried around in the field. The device works continuously for about 8 hours with two AA cell batteries. The GPS signal data received from the satellites are recorded onto a SD memory card. The GPS signals can be received by either built-in or external antenna; we used the built-in antenna, which is most practical. This DGPS device is capable of differential correction of GPS signals by two means: real-time SBAS (Satellite-Based Augmentation System) correction and post-processing correction. The SBAS correction uses another signal comprising correction information, such as atmospheric conditions, which is transferred

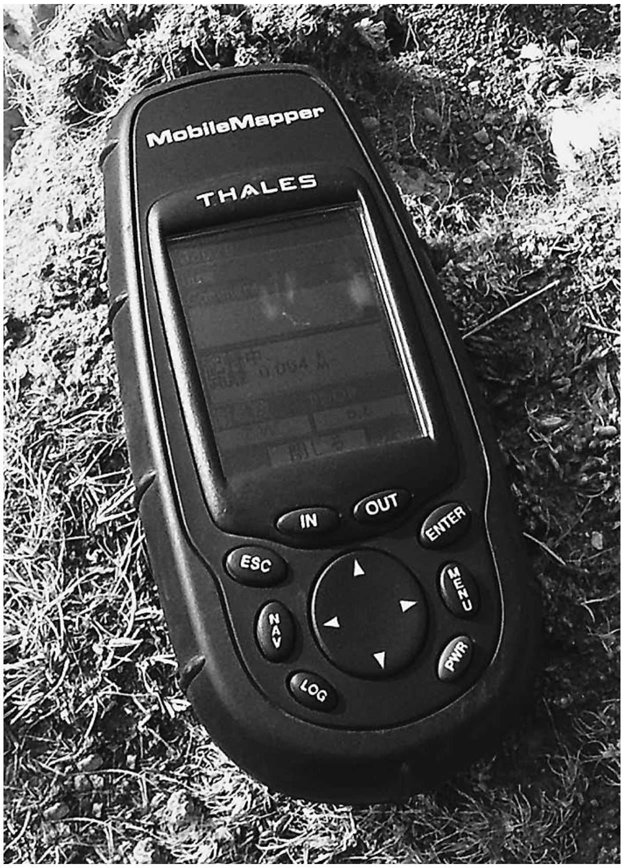

Fig. 1 DGPS device tested (MobileMapper Pro by Magellan Navigation Inc.).

from ground-based public measurement stations. GPS measurement with SBAS correction can be carried out by a single device. The SBAS in the American region is named WAAS (Wide Area Augmentation System), in Europe EGNOS (European Geostationary Navigation Overlay Service), and in east Asia MSAS (MTSAT-based Satellite Augmentation System). The manufacturer's stated accuracy of position measurements with SBAS correction is 2–3 m. Another method of differential correction uses two or more devices for measurement, one of which is used as a base station and others as mobile stations. The recorded GPS signals in the devices are collated after measurement to carry out differential correction, so the method is called post-processing correction. The manufacturer's stated position accuracy after post-processing correction is less than a meter (Thales Navigation 2004).

DGPS measurements were carried out at two sites, Kaman (39°20'42"N, 33°47'24"E) and Hacıtuğrul (39°42'20"N, 32°13'16"E) in central Anatolia, Turkey. Measurement of DGPS positioning for a relatively short time duration was undertaken at Kaman, and measurement for a relatively long duration was undertaken at Hacıtuğrul as a component of topographic measurement of the tepe. The two sites have similar conditions of latitude, climate and vegetation, and the reception status of GPS signals was almost the same for the two sites, with open sky (almost no shielding by topographic reliefs, trees and/or buildings), fair weather, dry air condition and daytime air temperature of ca. 30–40°C. DGPS measurements were made over a 200- to 300-m diameter area at Kaman and ca. 1-km diameter at Hacıtuğrul.

Three DGPS devices were used for the measurements, one of which was set as the base station and the other two as mobile stations. The base station was set at a fixed location at each site on each day. Measurement readings with the mobile devices were taken with differing measurement durations. At Kaman, the measurements were taken with a relatively short duration (~15 min); 131 measurements were taken, all in one day (July 23, 2007). At Hacıtuğrul, the measurements were taken with a relatively long duration (~ 40 min each); 114 measurements were carried out over 10 days between July 25 and August 8, 2007.

After the field measurements, the DGPS data were imported into a PC via SD memory card, and the DGPS log data of the base and mobile devices were post-processed using bundled software (MobileMapper Office), giving corrected coordinates of the measured points in the UTM projection (Zone 36N).

RESULTS AND DISCUSSION

Accuracy by SBAS-based differential correction at base station

The DGPS logs measured at each base station were corrected based only on SBAS information, and here we show daily changes of the SBAS-corrected coordinates of the base station device at Hacıtuğrul during the 10-day measurement (Fig. 2). The daily average horizontal coordinates of the base station (XY in the UTM projection), as well as the average vertical coordinates

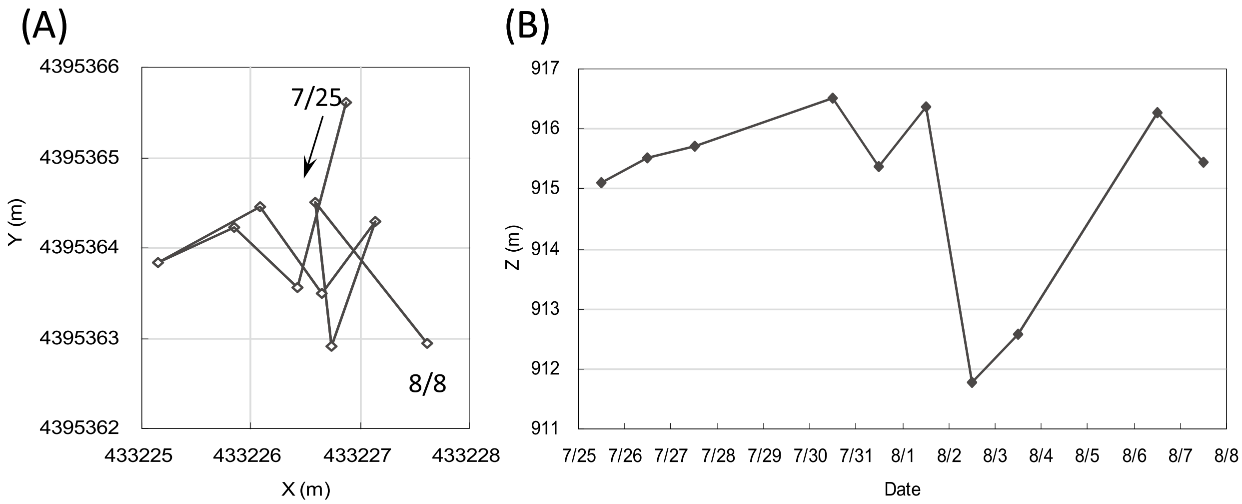

Fig. 2 Daily changes of position coordinates of DGPS base station. (A) Horizontal coordinates in UTM Zone 36N projection. (B) Elevation.

(Z), change by up to 2.8 m and 4.8 m, respectively, despite the fixed location of the DGPS base device on the land surface. These values, no better than the manufacturer's stated accuracy (2–3 m), represent actual accuracy with the SBAS differential correction at this site. The overall measurement period each day was 4–6 hours, so the lower accuracy was not due to insufficient measurement duration. The fluctuation of the coordinates on the order of meters therefore represents the ability of SBAS correction even when the measurement duration is sufficiently long. At the study sites, the available SBAS satellites (EGNOS) are located at a low angle in the sky, and thus the SBAS correction might work relatively ineffectively.

Accuracies by post-processed differential correction for mobile stations

Using the post-processing software (MobileMapper Office) designed for the DGPS devices, the measured GPS log data, comprising number of satellites captured, PDOP (position dilution of precision) and measure duration, are retrieved and "horizontal error" and "vertical error" are automatically computed. Since these "errors" rely solely on the log data, they should be further examined with some other comparable data having better accuracy, for more robust assessment. These "errors" are therefore regarded as an index of the absolute or true error.

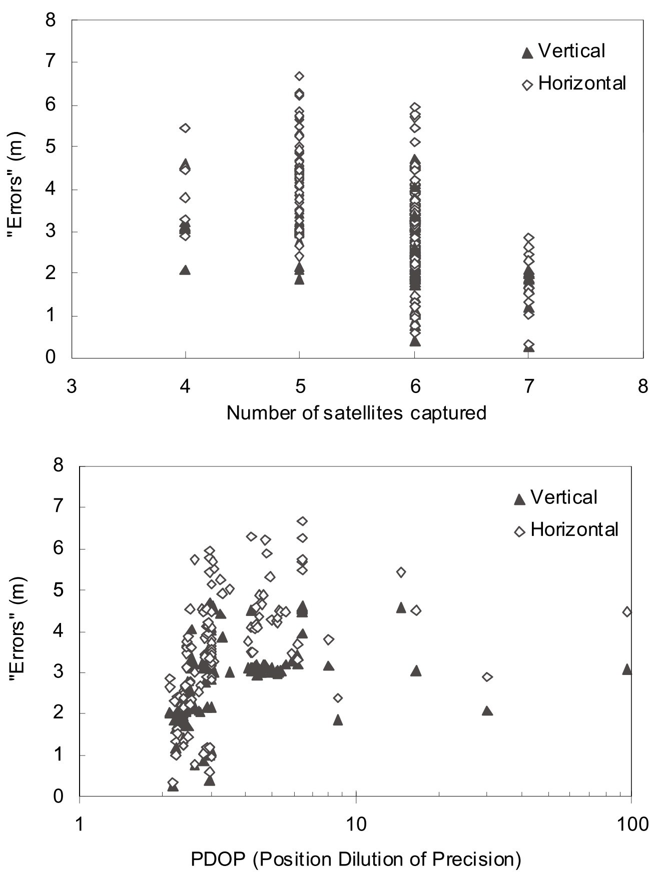

Fig. 3 Relationships between number of satellites, PDOP and horizontal and vertical errors, based on two DGPS devices used as mobile stations at Kaman.

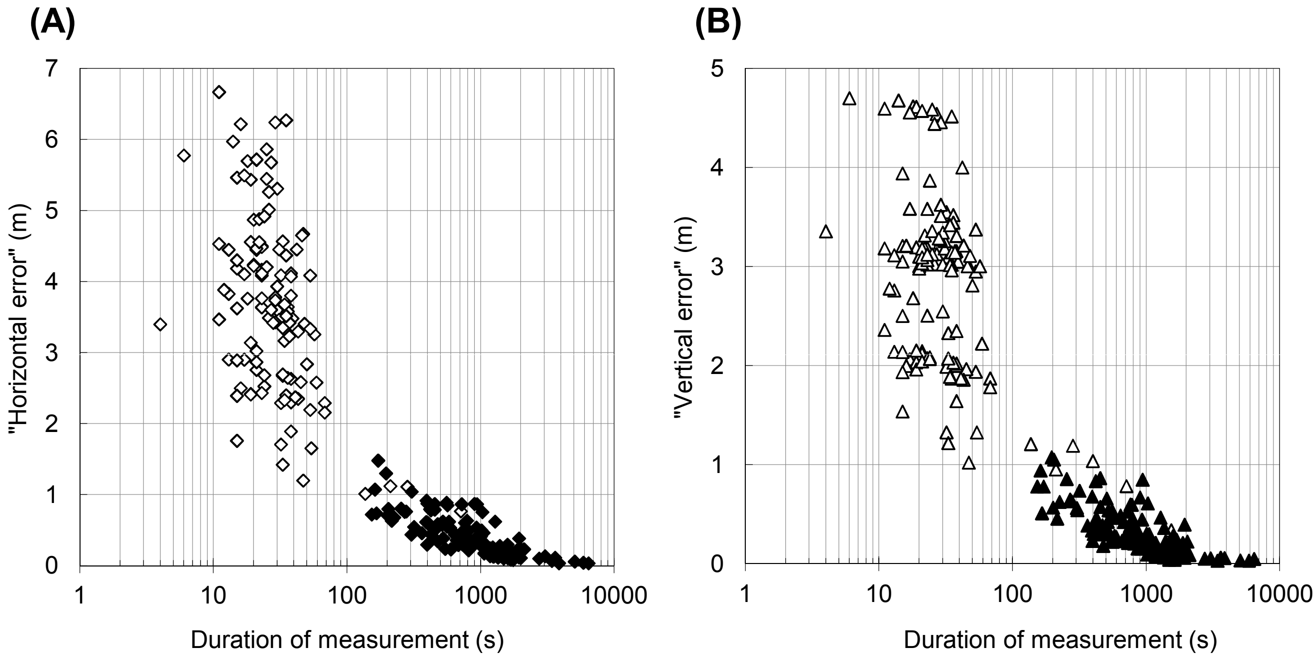

Fig. 4 Relationships between measurement time and horizontal (A) and vertical (B) errors. Outlined symbols are the data of Kaman, and black solid ones are the data of Hacıtuğrul.

Table 1. A summary of relationships between measurement duration and the error of post-processed DGPS coordinates

Duration of measurement (min)	Position errors after post-processing correction
< 2	1 - 7 m (no dependence on duration)
2	ca. 1 m
10	All data are less than 1 m
20	All data are less than 0.5 m

In general, the accuracy of GPS positioning is better when the number of satellites captured is larger, or the PDOP value is smaller. Our data at both Kaman and Hacıtuğrul show that the error value tends to be small, especially when the number of satellites is more than 6 and/or the PDOP value is less than 3 (Fig. 3), although the full relationship between errors versus number of satellites and PDOP is unclear. The error seems to be much more clearly related to the measurement duration (Fig. 4), suggesting the dominant effect of measurement duration on the accuracy of DGPS measurement.

According to these data, measurement duration should be no shorter than 2 minutes in order to let the horizontal and vertical errors be less than ca. 1 m, in turn, to give the accuracy of 1 m. Furthermore, more than 10-minute duration is necessary to make all the errors less than 1 m, and more than 20-minute duration is needed for the errors to be less than 0.5 m. In contrast, when the duration is shorter than 2 minutes, the errors do not correlate with the measurement duration and fluctuate within the range of 1 to 7 m (Fig. 4, Table 1). These values are below the manufacturer's stated accuracy of the DGPS device (<1 m), indicating that measurement duration shorter than 2 minutes is insufficient for post-processing correction.

CONCLUSIONS

This paper examined the accuracy of a post-processing DGPS device for field studies. The accuracy or errors of DGPS positioning with post-processing differential correction is dominantly affected by the duration of the measurement. It was found that 2 minutes is the minimum necessary time to enable efficient post-processing differential correction for the DGPS devices used. The position accuracy of SBAS-based differential correction is several meters, even when the measurements are taken over a period as long as 6 hours.

Further assessments of other GPS devices are necessary to generalize these results, with different types of GPS in different areas under various conditions. Nonetheless, when using any kind of device, it is important to examine and quantify the practical ability of such devices prior to actual use in field survey. As a matter of course, this kind of analysis on the accuracy of devices is often necessary for the users, even if the vendor provides such information on the specification and characteristics of the devices.

It should be noted that some troubles in device operation occurred during the survey: for instance, the liquid crystal displays of two of the devices were malfunctioned and the display barely worked. The most serious trouble was corruption of data written to the SD memory card in the device, and this frequently caused loss of some of the DGPS log data. Furthermore, failures in finalizing the GPS log data occurred when the battery died or at accidental shut-down of the device. These troubles may have occurred due partly to the strong sunlight and heat at the sites, although such troubles also occurred later in other areas (such as in Japan) without strong sunlight. The device itself may have some vulnerability in the display and memory systems, and their cause should further be investigated by the provider of the device. We users, however, should also be careful to avoid accidents in devices we use in the tough environments of field survey.

BIBLIOGRAPHY

Fenwick, H.
2004 "Ancient roads and GPS survey: modelling the Amarna Plain," *Antiquity* 78, pp. 880–885.

Hayakawa, Y. S., and K. Kashima
2006 "Topographic map construction using a handheld laser range finder and GIS at Kaman-Kalehöyük and Kültepe," *AAS* XV, pp. 191–195.

Hayakawa, Y. S., T. Oguchi, J. Komatsubara, K. Ito, K. Hori and Y. Nishiaki
2007 "Rapid on-site topographic mapping with a handheld laser range finder for a geoarchaeological survey in Syria," *Geographical Research* 45 (1), pp. 95–104.

Miyahara, K.
2006 "GPS TO ISEKICHOUSA NYUMON (Introduction to GPS and archaeological excavation)," in: T. Uno (ed.), *JISSEN KOUKO-GAKU GIS (Practice in Archaeological GIS)*, NTT Press, pp. 33–38 (in Japanese).

Thales Navigation
2004 *White Paper: MobileMapper Post-processed Accuracy*, Thales Navigation.

Takahashi, A., T. Oguchi and H. Sugimori
2003 "Effects of Digital Elevation Model resolution on topographic representation: A case study in the Tama area, western Tokyo," *Geographical Review of Japan* 76, pp. 800–818.

Tsumura, H., and S. Suzuki
2006 "The Archaeological Informaics and Spatiotemporal Digital Archive System (AISDAS) – 1. GIS-based investigations in Kaman-Kalehöyük and surrounding areas using AISDAS," *AAS* XV, pp. 181–189.

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