Multi-applications of GPS for Hydrographic Surveys

C. C. Chang, H.W. Lee and J. T. Lee

Department of Surveying and Mapping Engineering, Chung Cheng Institute of Technology

Tahsi, Taoyuan 335, Taiwan, ROC

I. F. Tsui

Naval Hydrographic and Oceanographic Office, Tsouing, Kaohsung 813, Taiwan, ROC

Abstract. A multi-antenna GPS system was designed and applied mainly to the so-called 'tide-independent' bathymetric measurements. It aimed at improving the accuracy achieved by the traditional technique, in which the tidal observations required were made at the tide gauges along the coast. The attitude parameters of the vessel, estimated by the GPS system, can also be introduced to the corrections for the bathymetric measurements. The assessment using different correction modes, based on GPS solutions and applied to the bathymetric measurements, indicated that the measurement quality has been significantly improved by the tide-independent technique. The accuracy of bathymetric measurements has shown the improvement of up to 47%, and fully satisfied to the first-order standard of the international hydrographic survey. The offshore tidal observations, relied on the vessel-based GPS system, were also effectively made by the vertical component of the GPS solutions. The average agreement between the observations from the GPS solutions and tide gauge records has found to be better than 3 cm, based on the field tests carried out nearby the Hsinchu Harbor located at the northwestern coast of Taiwan.

Keywords. GPS, hydrographic surveys, bathymetric measurement

1 Introduction

The bathymetric and tidal data are the major measurements of hydrographic survey. The nautical chart based on those high precision measurements is of importance, particularly for those major trading nations, such as Taiwan. A great demand is consequently placed on hydrographic surveyors to provide the high accuracy and up-to-date charts for either navigation systems or engineering applications.

As the survey vessels normally take measurements in a 'dynamic' environment varied with the sea surface, it is almost impossible to instantaneously collect the 'ideal' bathymetric measurements truly vertical to the mean (or initial) sea level. This difficulty, however, can be solved with the mathematical methods by introducing the attitude parameters of the vessel, composed of the roll, pitch, heading, and heave, into the bathymetric corrections (Blagoveshchensky (1962)).

Traditionally, a well-equipped survey vessel must carry the inertial system, motion sensor, and other electronic instruments to provide the information of the attitude parameters. Those sensors, normally expensive and not portable, are basically mounted on heavy tons of vessels only and not suitable to be used over the shallow seabed in the Taiwan Strait.

The GPS has been the most recent and important advance in space positioning techniques over the last two decades. One purpose of this study was to use a multi-antenna GPS system, easy-mounted on a light vessel, to precisely determine its attitude parameters through the combinations of the GPS vectors (Lu and Cannon (1994), Rapatz (1991)). The vessel carrying the GPS system can also implement the so-called 'tide-independent' bathymetric measurements, where the tidal data conventionally read from the pier-mounted tide gauge are no longer required (Phelan (1998)). Moreover, the tidal observations made at the offshore area also become possible by analyzing the height data collected by the GPS system on board, where the vessel was regarded as a steady 'buoy' floating on the sea surface (Deloach (1995), Moore et al. (2000)).

2 System Design and Field Tests

To ensure a platform in the space, at least two non-collinear vectors or three non-collinear points are required. An antenna platform tested on the vessel, consisting of three GPS antennas, was defined as Figure 1 and operated as Figure 2 during the field tests. The GPS vectors between each two antenna phase centers were relatively determined from a base station on the pier, with 10-second data intervals and post-processing kinematic phase solutions, referred to the so-called 'TWD97' three-dimensional coordinate system in Taiwan (Chang and Tseng (1999)).

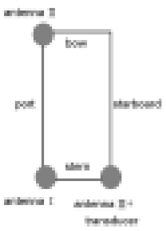

Fig. 1 GPS Antenna Platform Designed on Board

Fig. 2 GPS System Operated during the Field Tests

The roll, pitch, and heading of the vessel can be solved with the vector combinations that have been transformed into a local coordinate system originated at one of the antenna (Ziljoski et al. (1999)). Those attitude parameters can then be introduced into the corrections for bathymetric measurements. Furthermore, the height solutions of the GPS antenna (h_{GPS}) can also be combined with the measurements read by the transducer (d_{obs}), the offset between the GPS antenna and the transducer (d_{offset}), and the geometric height of the sounding datum (h_{sd}) to carry on the 'tide-independent' bathymetric measurements. The relationship is shown in Figure 3, and expressed as

$$d = d_{obs} + d_{offset} - h_{GPS} - h_{sd} \qquad (1)$$

where d denotes the bathymetric measurements required.

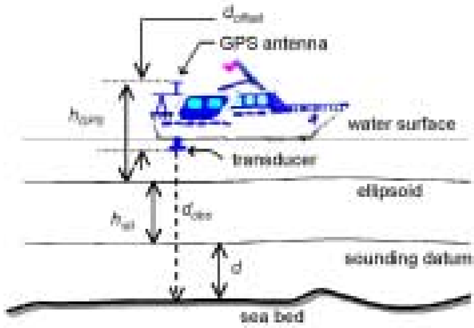

Fig. 3 Tide-Independent Bathymetric Measurement Based on GPS

The GPS height solutions can also be a part of the basic measurements to the offshore tidal observations. Two-stage survey has to be conducted by initially anchoring the vessel in the harbor to establish the distance from the GPS antenna phase center to the water surface (h_{ws}) with the GPS heighting (h_{GPS}) and tide gauge data(h_b and T_{obs}). It is expressed as

$$h_{ws} = h_{GPS} + h_{sd} - h_b + T_{obs} \qquad (2)$$

The vessel can then drive to the offshore area to estimate the tidal height at every measuring point (h_{tide}), mainly based on its GPS solution (h_{GPS}). The geometric relationship for the offshore tidal observations is depicted in Figure 4, and expressed

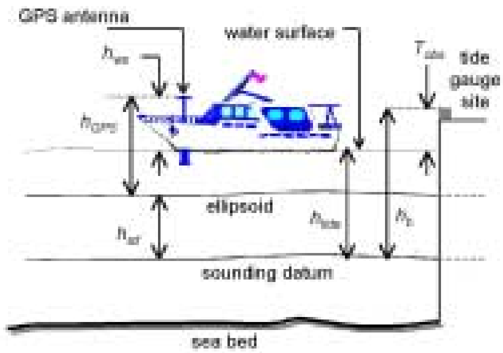

Fig. 4 Tidal Observation Using GPS on Board

as

$$h_{tide} = h_{GPS} - h_{ws} + h_{sd} \qquad (3)$$

Four sets of field tests, based on using the multi-antenna GPS system designed, were carried out for hydrographic surveys in 1999. Four dual frequency GPS receivers, two Ashtech Z-Surveyor and two Leica SR-9500 receivers, were mainly used by the tests. The test area covered the Hsinchu Harbor and an offshore area four kilometers away from the harbor. The relevant information for these four sets of field tests is now summarized in Table 1.

Table 1. Information for the Hydrographic Field Tests

Data Set	Date	Operation Mode	Sea State
1	19/07 /1999	Attitude Parameters Determinations	Wind Scale: 5-6 Gust Scale: 8
2	20/07 /1999	Tidal Observations (Offshore)	Wind Scale: 4-5 Gust Scale: 7
3	15/09 /1999	Tidal Observations (Nearshore)	Wind Scale: 4-5 Gust Scale: 7
4	12/10 /1999	Bathymetric Measurements	Wind Scale: 5-6 Gust Scale: 8

3 Test Results and Discussions

3.1 Determinations of Attitude Parameters

The track of the vessel during the first set of test can be plotted in Figure 5, based on the coordinates from the GPS solutions. The attitude parameters, including the roll, pitch, and heave of the vessel solved from the first data set, are now shown in Figure 6, Figure 7, and Figure 8, respectively.

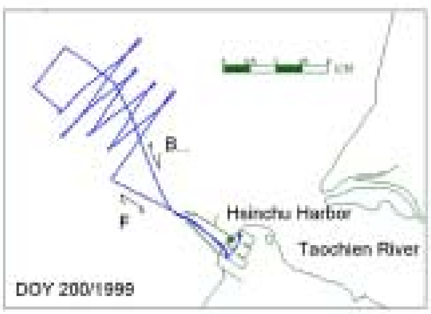

Fig. 5 Vessel Track for the Test of Attitude Determinations

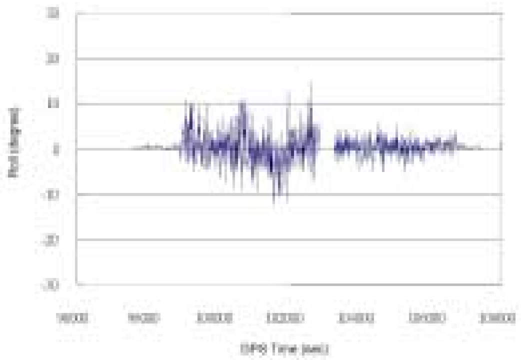

Fig. 6 Variations of Roll Angle Estimated from GPS Antenna Vectors

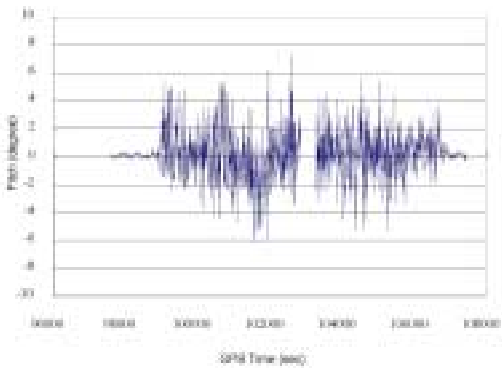

Fig. 7 Variations of Pitch Angle Estimated from GPS Antenna Vectors

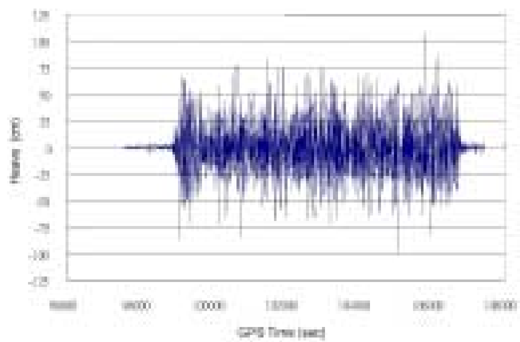

Fig. 8 Variations of Heave Estimated from GPS Heighting

It can be seen from Figure 6 and Figure 7 that the roll angles are generally larger than those of pitch, caused by the flat-bottom type of vessel in use. Those variations show a standard deviation of 3 degrees in roll and 2 degrees in pitch, and a maximum roll and pitch of 14 degrees and 7 degrees, respectively. The variations of heave show a standard deviation of 26 cm, along with the maximum value of 102 cm.

To estimate the precision of the GPS solutions for the data collected, the variations of the lengths of GPS antenna vectors were investigated. This is based on the constrain that the baseline length between any two GPS antennas on board must be kept as fixed during the test. The variations of the lengths, differred from the average, are now shown in Figure 9 for the baseline between GPS antenna I and II.

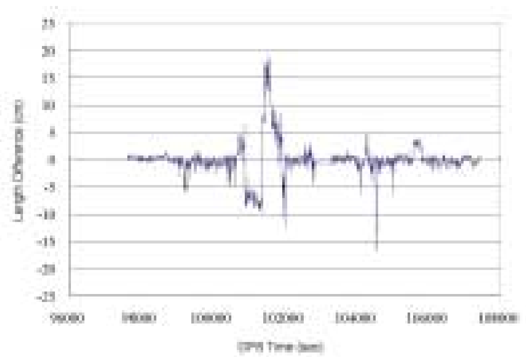

Fig. 9 Variations of Length Difference for GPS Antenna Vector I-II

It can be realized from Figure 9 that the baseline length differences varied slightly at the beginning and ending of the test when the vessel was driving near to the harbor with less influence from the sea state. The precision of the GPS solutions can be estimated from the scatter values of the length differences for the GPS antenna vector I-II, I-III, and II-III, where the average standard deviation is 2.3 cm.

3.2 Tide-Independent Bathymetric Measurements

The fourth set of data was collected and tested for the effectiveness of different correction modes introduced into the bathymetric measurements. The vessel track is shown in Figure 10 for this set of test. The correction modes applied to the bathymetric measurements, mainly based on the attitude and height corrections obtained from the GPS system, are summarized in Table 2.

To investigate the effectiveness of those correction modes applied to the bathymetric measurements, the differences between the measurements made at the cross points of different vessel tracks were assessed. A total of seven check points, defined by the cross points with a range difference of less than 5 m, was selected. According to the specification of first-order bathymetric measurement, the absolute difference value for the check point must be better than 63 cm, based on the sea depth of 30-40 m in the test area (IHB (1998)). The assessment to the bathymetric corrections, applied with the modes listed in Table 2 for those check points, is now listed in Table 3.

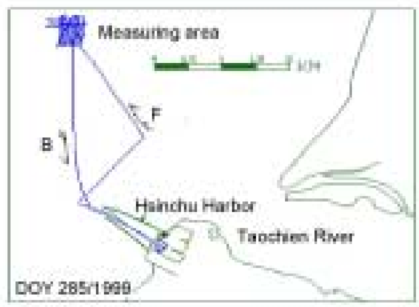

Fig. 10 Vessel Track for the Test of Tide-Independent Bathymetric Measurements

Table 2. Correction Modes Applied to the Bathymetric Measurements

	Attitude Corrections	Height Corrections (using one of the two below)		
Mode	Roll	Conventional	GPS	
	and Pitch	Heave	Tide	Tide-independent
1	N/A	N/A	Applied	N/A
2	Applied	N/A	Applied	N/A
3	N/A	Applied	Applied	N/A
4	Applied	Applied	Applied	N/A
5	N/A	N/A	N/A	Applied

6	Applied	N/A	N/A	Applied

It can be clearly seen from Table 3 that the attitude and height corrections play a very important role in the bathymetric measurements, where the measuring errors can be reduced by 10-24 cm. The accuracy was significantly improved by 43% or 47% when Mode 4 or Mode 6 was introduced, both based on the completed use of attitude and height corrections to the measurements. The accuracy was futher improved from Mode 4 to Mode 6, as the height corrections made by the tide-independent GPS method were applied. The accuracy improved from Mode 3 and Mode 5 also showed the effectiveness of using tide-independent GPS method for bathymetric measurements. The highest passing rate and the only mode that satisfied with the requirement of the first-order standard was shown with Mode 6. It is, hence, realized that Mode 6 introducing attitude corrections and using tide-independent technique for height corrections, both based on the GPS system on board, appears to provide the most accurate and reliable bathymetric measurements.

Table 3. Effectiveness of Correction Modes Applied to the Bathymetric Measurements

Mode	Average Absolute Difference (cm)	Improvement to Mode 1 (%)	Satisfied to Specification (ratio)
1	51	N/A	5/7
2	37	28	6/7
3	41	20	4/7
4	29	43	6/7
5	38	26	5/7
6	27	47	7/7

3.3 Offshore Tidal Observations

Tidal observations are required by many hydrographic surveys. The second and third data sets collected during the fieldwork were designed to test a vessel-based GPS system as a 'buoy' measuring tides on the open sea. These two sets of test were carried out by anchoring the vessel inside the harbor and on an offshore area, respectively, to collect the data required (see Figure 11). It aims at assessing the accuracy of the tidal observations, and investigating the effectiveness of the vessel-based GPS system.

The tidal observations using vessel-based GPS system, tested both in nearshore and offshore, were processed with a 6 minute span as the tidal data measured by the pier-mounted tide gauge, treated as the standard values for the accuracy assessment, were provided with the same interval by the Central Weather Bureau. The comparisons between the tidal observations based on GPS system and tide gauge are now shown in Figure 12 and Figure 13 for the tests carried out in the nearshore and offshore area, respectively.

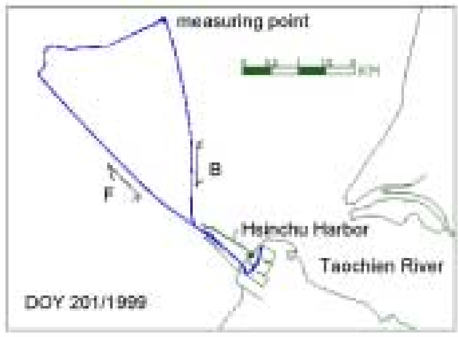

Fig. 11 Vessel Track for the Test of Offshore Tidal Observations

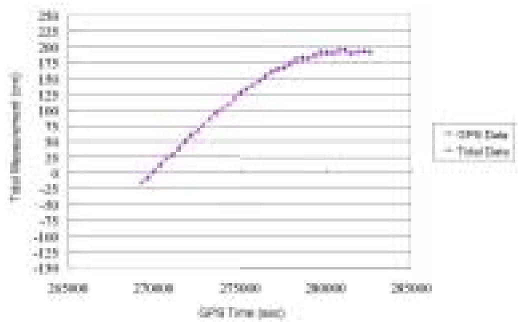

Fig. 12 Comparisons of Tidal Observations in Nearshore

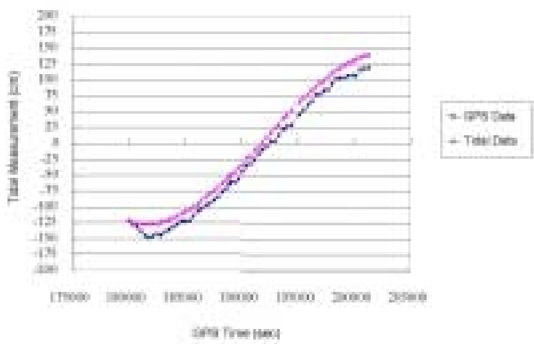

Fig. 13 Comparisons of Tidal Observations in

Offshore

The differences between the tidal data recorded by tide gauge and observed by vessel-based GPS system were found to have different fittness. The average difference was estimated to be 2.8 cm for tidal observations in nearshore（see Figure 12）. The differences were increased to a range of 10-25 cm when the vessel carried on tidal observations in offshore（see Figure 13）. The differences increased can be explained by the sea state getting worse and the off-site tidal observation errors for the offshore area (USACE (1991)). It was also believed that the tidal differences appeared in Figure 13 were related to the SAS (Settlement and Squat) caused by the vessel's weight, shape, relative speed to the sea water, and the depth of the sea water, ect. (USNOS 1999)). The accuracy of the offshore tidal observations using vessel-based GPS system is expected to be further improved by installing auxiliary tools that can detect the SAS effect and provide the relevant corrections to tidal observations.

4 Conclusions and Suggestions

This paper has widely shown the test results for the multi-applications of the vessel-based GPS system carrying on the hydrographic surveys. The low-cost and high-efficiency GPS system used on board has been tested to be helpful for bathymetric measurements by effectively determining the attitude parameters, and implementing the tide-independent measurements. The accuracy of the bathymetric measurements was improved by 47% when the attitude and height corrections based on the GPS solutions were applied. The vessel-based GPS system has also shown its availability for the tidal observations carried on in the offshore area. The accuracy was estimated to be around 3 cm in nearshore and 10-25 cm in offshore from the test results. This level of accuracy can be expected to improve by detecting the biases related to the movements of the vessel and the variations of the sea surface.

Acknowledgments

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