Dynamic Baseline Survey of Marine Buoys with respect to a Moving Vessel Ashtech G-12 Receivers and Waypoint's High Precision GrafMov Software

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The following report details one survey in an extensive series of tests carried out by James Doutt of The Woods Hole Oceanographic Institution (WHOI) utilizing Ashtech G-12 GPS receivers and Waypoint's GrafMov relative moving baseline software package. The results presented here are a typical sample of the surveys performed during the Modal Mapping experiment on RV Endeavor cruise #EN-297 (21 March - 3 April, 1997) by George Frisk, Chief Scientist.

The given task in these surveys was to measure the baseline distances from one or both of the two antennas mounted on a moving vessel to buoys drifting at distances of up to several kilometres from the ship. The original specification for the tests was for reliable sub-metre accuracy from ship to buoy. In general, results of the tests indicate that given reasonable GPS satellite geometry (i.e. 6 satellites in view), the combination of G-12 receiver and GrafMov software provided sub-10 cm range information from the ship to the moored buoys.

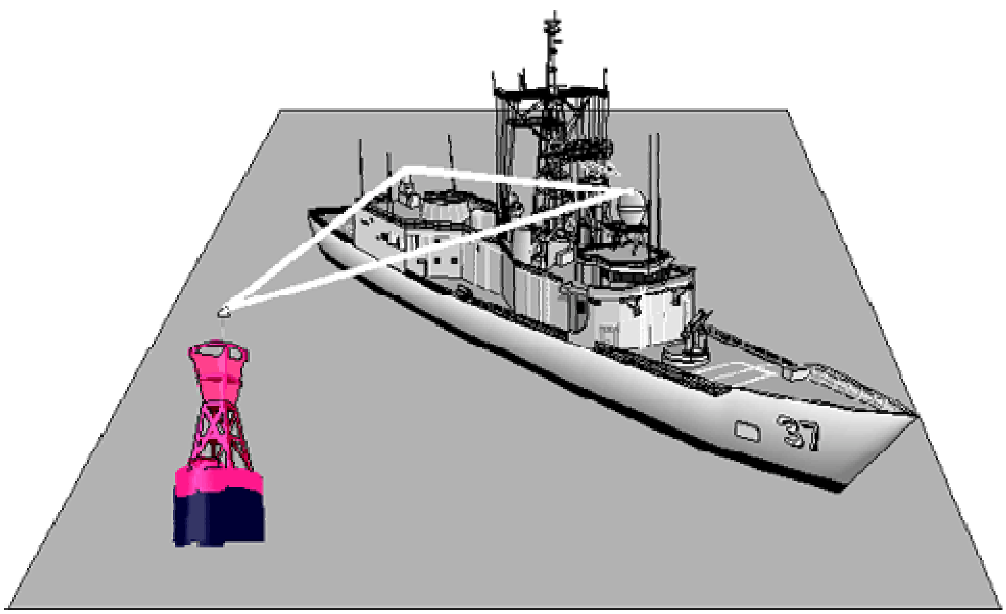

Figure 1: Research Vessel - Forward and Stern Antennas to Buoy

The purpose of the Woods Hole mission was to determine the ranges from ship to buoy in support of shallow water sound transmission experiments. A sound source was towed from the stern of the ship, and a hydrophone was suspended beneath each drift buoy. The sound field produced as the ship changed range with respect to the buoys was recorded and analyzed to provide information about the variability of shallow sediments beneath the sea floor.

The problem from a GPS perspective is that the base station is actually a moving platform. No static initialization is possible in any case since the remote stations are buoys that are under constant wave motion. Furthermore, cost constraints prevented the use of dual frequency receivers.

One of the high quality single frequency GPS OEM receiver cards available is the Ashtech G-12. From previous experiments conducted by Waypoint Consulting, it was felt that this receiver could reliably perform single frequency on-the-fly ambiguity determination in a reasonable GPS environment on short baselines of less than 5 km, provided 6 or more satellites were available. Waypoint's GrafMov software has already proven in previous ground and airborne tests that in a moving baseline situation, relative base to remote antenna accuracies of centimetre-level precision are possible.

In a scenario of this type where two antennas are fixed to the ship for base station redundancy, there are two obvious ways of quantifying GPS accuracy. The first is to measure the spatial distance between the forward and stern antennas. This measured slope distance must remain constant, no matter what the orientation or sea-state that the vessel is experiencing. At any given GPS epoch, the spatial distance from the bow to stern antenna can be computed as a function of the moving baseline derived local level coordinates at that instant. In the case presented in Figure 1, the measured distance between the two ship-mounted antennae was 28.11 m. Figure 2 displays the epoch by epoch GPS derived distance between the fixed antennae.

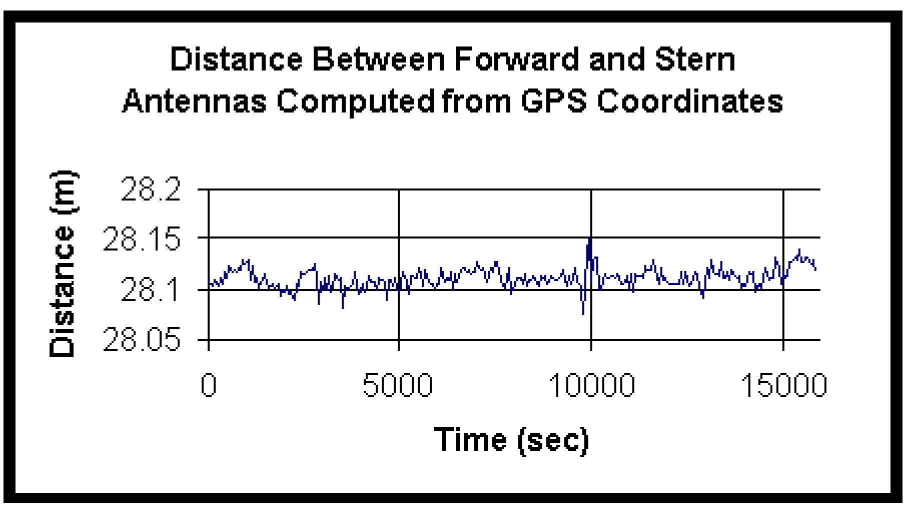

Figure 2: GPS Computed Distance from Foward to Stern Antennae

Unfortunately, while this measure of precision does provide some idea of the possible accuracy of the GPS system, it certainly does not say anything about the accuracy of the GPS derived ranges to the target buoy. What is required then, is a method of qualifying the range accuracy from the vessels base stations (forward and stern) to the remote antenna on the buoy. A simple way of assessing the internal accuracy of the coordinates generated from 3 baselines (forming a triangle) is to recognize that the sum of any of the coordinates of the vertices of a triangle must equal zero. Figure 3 illustrates this in terms of a vector sum.

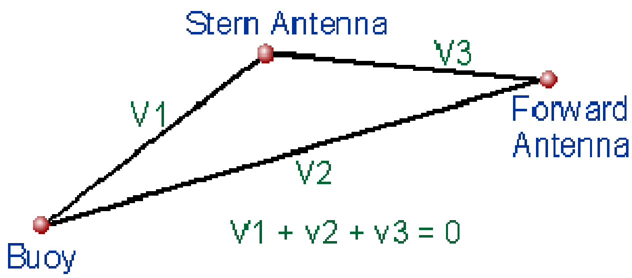

Figure 3: The Sum of the Coordinates in the 3 Baselines Should be Zero

If GrafMov is used to process the baselines between all 3 antennas for each GPS epoch, the results of a summation of the relative local level coordinates at any GPS time should provide an estimate of the error in the GPS determination of the range to buoy. In fact, this is really a check on the errors in the single frequency OTF determination of the L1 phase ambiguities on each baseline. Some cancellation of errors can be expected in this type of error check, but it is also unlikely that the triangle coordinates will close to something close to zero unless the individual baseline ambiguities have been determined more or less correctly.

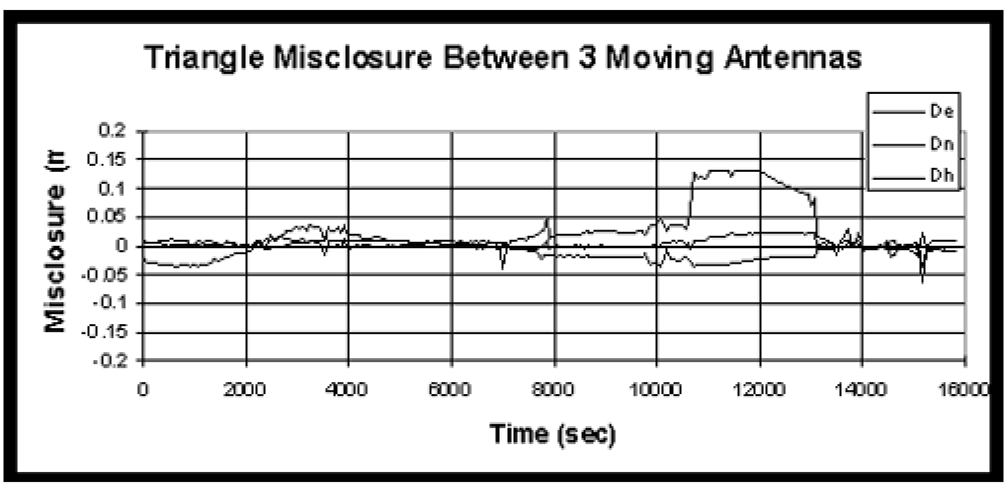

Figure 4: Triangle Coordinate Misclosures for the Mission

Figure 4 illustrates the results of adding the sum of the delta east, delta north and delta height coordinates for each moving baseline solution of the 3 vectors which form the triangle from ship antennas to the remote buoy antenna. Refer to Figure 1 for a more pictorial graphic of the problem.

This survey was processed using GrafMov's single frequency OTF functionality. OTF was performed utilizing about 5 minutes of kinematic data at the start of the mission. GrafMov restores any ambiguities prior to OTF by searching backwards in the data for GPS times and satellites that correspond to the ambiguities computed at the successful OTF epoch.

It can be readily seen that for the entire mission the sum of the horizontal coordinates is less than 0.05 m. There is a small vertical problem of about 0.12 m apparent from epoch 10500 to approximately epoch 13000, otherwise the vertical component is also sub-5 cm. This corresponds to a period of 5 satellite geometry during which time PRN 17 remained low on the horizon and subject to low elevation tropospheric effects. It is felt that the data could have been re-processed with a processing command issued to re-do OTF for this period, but given the mission parameters, which in fact demand sub-metre accuracy, the precision shown in the graph above more than sufficed for the task specifications.

Another concern raised before this series of surveys began was the issue of possible detrimental multi-path effects from both boat and water reflections. In fact, it can be seen from the GrafMov plots, in Figure 5, that multi-path in this environment was not really a problem for the G-12 GPS receiver.

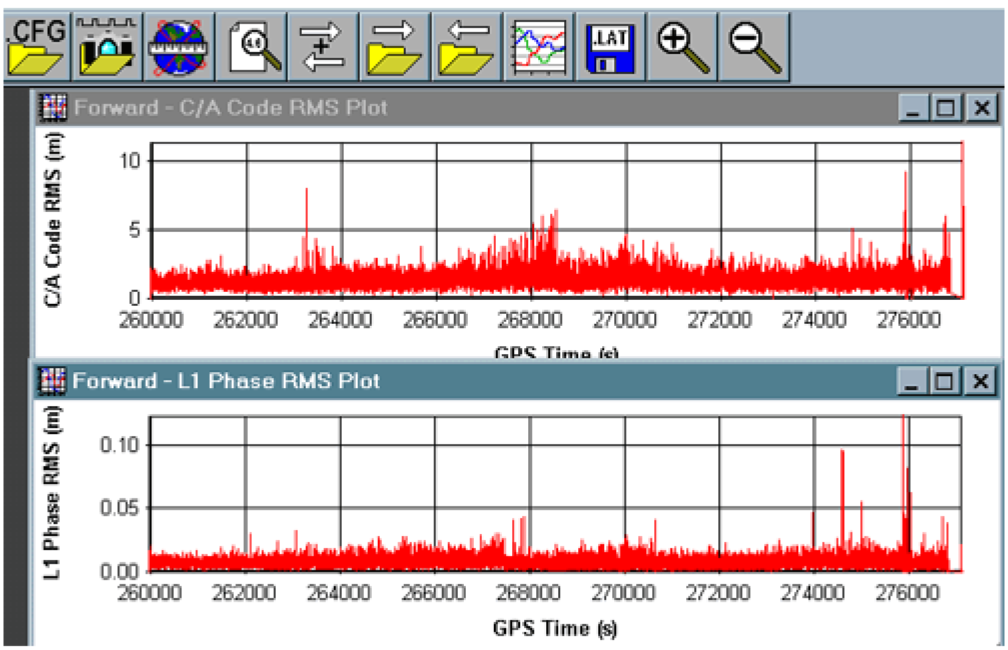

Figure 5: GrafMov Plot of Code and Phase Noise in this Environment

It can be readily seen from the magnitude of the RMS measurement residual plots, in Figure 5, that while some colored noise exists due to multi-path effects in this survey, the G-12 stays within acceptable noise levels given the somewhat rigorous environment.

Outside the scope of this survey, but of interest to mariners is the fact that the forward / stern antenna configuration does not merely provide distance but local level or true north azimuth, as well. This is the same azimuth produced by heading gyros and it may be worth examining the possibility of augmenting, calibrating or replacing ship-borne gyros with moving baseline GPS. The real-time version of GrafMov computes this quantity.

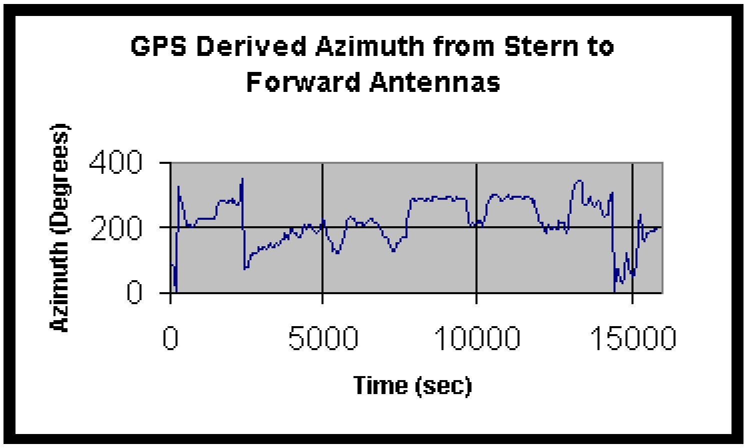

Figure 6: Vessel's Azimuth Computed from GPS Forward / Stern Antennae

It should be noted that the error in the derived azimuth is proportional to the GPS error divided by baseline length of the forward to stern antennas. An error of 0.05 m in the GPS coordinate determination over the 28.11 m baseline translates to an azimuth error of about 0.10 degrees.

Conclusions

A moving baseline marine GPS survey conducted by Woods Hole Oceanographic Institution has been described. This survey utilized Ashtech G-12 single frequency receivers in concert with Waypoint's GrafMov high precision relative baseline post-processing software. A research vessel mounted with 2 antennas was used as a base station. Two antennas were used for redundancy and error analysis of the GPS coordinate determinations. A by-product of the forward / stern antenna configuration is precise computation of vessel heading. A remote buoy was fixed with a GPS antenna and G-12 receiver. The purpose of the survey was to determine the epoch by epoch range from the moving ship to the remote buoy. It has been shown that the G-12 receiver is capable in this environment of providing sub 5 centimetre horizontal coordinate determination in a environment not usually associated with GPS, that is a moving vessel to a non-stationary target.