A LAGRANGIAN DRIFTER WITH INEXPENSIVE WIDE AREA DIFFERENTIAL GPS POSITIONING

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Abstract -Autonomous drifting buoys that acquire position data using Global Positioning System (GPS) navigation have proven valuable in Lagrangian measurement applications requiring greater accuracy and data density than is available through other technologies such as ARGOS satellite tracking. The limits on measurement accuracy in a GPS drifter are set by the geographic accuracy of the GPS position. Standard civilian receivers are affected by the purposeful degradation of GPS accuracy (termed Selective Availability or SA), which result in position measurement inaccuracies of up to +/- 100 meters. A 100 meter error over a 30 minute timespan between drifter positions results in a 6 cm/sec error in computed current velocity, a potential error which grows larger as shorter position recording intervals are used. Improvement of the accuracy of GPS positioning would allow use of GPS drifters in an even wider range of current measurement applications that demand fine spatial and temporal resolution.

Differential GPS (DGPS) refers to a technique that uses GPS data from a reference station at a well known location to calculate corrections that are then used to improve the accuracy of GPS positions at a less well known location. DGPS can increase the accuracy of standard civilian receivers to +/- 20 meters or better. Conventional DGPS relies on real-time telemetry of correction data from one or more reference station to the GPS receiver that requires correction. This method can be difficult, expensive, and is not available at all locations. A drifter equipped for conventional DGPS must have a telemetry receiver which adds cost and requires power. Moreover, the telemetry link must be maintained reliably during data acquisition or DGPS position accuracy is lost.

If real-time results are not required, however, a Wide Area Differential GPS (WADGPS) method can be used in post-processing to remove the effects of SA from drifter data. The requirements in the drifter are some additional data memory, minor firmware changes, and a GPS engine configured to output raw GPS satellite data (called "pseudoranges"). During a deployment, the pseudorange data is stored in drifter memory while standard GPS positions are telemetered and stored to assist in deployment logistics.

After retrieval, the pseudoranges are converted to DGPS-accurate positions using software and correction data provided by the Canadian Active Control System (CACS). CACS is a global network of automated GPS reference stations pioneered by the Canadian government for survey applications. Correction information is available from CACS at a modest fee with a few days delay from real time.

Dockside testing of WADGPS correction showed a reduction in 2 dimensional rms position errors from +/- 33.5 to +/- 9.3 meters. Several Brightwaters Model 104AV autonomous GPS drifters have been fitted with a WADGPS upgrade. A full field test of WADGPS correction of drifter data will be conducted in August 1996.

I. INTRODUCTION

Autonomous drifting buoys that acquire position data using Global Positioning System (GPS) navigation have proven valuable in Lagrangian current measurement applications that require greater accuracy and data density than is available through other technologies such as ARGOS satellite tracking [1]. Examples of these applications include calibration of ocean surface current radar, water mass tracking for larval fish ecology research, and general coastal current studies where tidal influences are large.

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Even the most economical GPS receivers can output data with time stamps accurate to much better than one second. The limits on measurement accuracy in a GPS drifter are therefore set by the geographic accuracy of the position obtained by the drifter's internal GPS receiver. For purposes of national security, the US military authorities which operate the GPS system purposefully degrade the accuracy of the signal available to civilian receivers. This degradation is termed "Selective Availability" (SA), and during normal system operation may result in position measurement inaccuracies of up to +/- 100 meters.

Although it is theoretically possible to have a drifter recording positions once per minute or even more often, the position uncertainty resulting from SA means that the practical limits for usable data are reached far sooner. For example, a 100 meter inaccuracy in position measurement in a drifter that is recording position every 30 minutes results in an error in the velocity measurement of

$$10000 \text{ cm} / 1800 \text{ sec} = 5.6 \text{ cm/sec}. \quad (1)$$

Table 1 lists the errors in velocity resulting from a 100 meter position inaccuracy at various recording intervals. From this table it is apparent that at recording intervals of less than 30 minutes the potential errors in velocity estimates quickly become large enough to be of great concern. Improving the accuracy of GPS positions would therefore be pivotal in allowing use of GPS drifters in applications requiring finer spatial and temporal current velocity resolution.

TABLE I
VELOCITY ERROR RESULTING FROM A 100 METER POSITION INACCURACY

Recording interval (minutes)	Velocity error (cm/sec)
30	5.6
20	8.3
15	11
10	17
5	33
1	167

Differential GPS (DGPS) refers to a technique that uses GPS data from a reference station at a well known location to calculate corrections that are then used to improve the accuracy of GPS positions at a less well known location. DGPS can increase the accuracy of standard civilian receivers to +/- 20 meters or better.

A conventional DGPS system is shown in Fig. 1. Signals from the GPS satellites are received simultaneously by the moving receiver (in our case the drifter) and by a second stationary receiver. Since the stationary receiver's location is known, deviations from the expected values of position are presumed to be errors. The stationary receiver calculates corrections for the data from each satellite. This corrections data is telemetered to the moving GPS receiver, where it is used to correct the position of the moving receiver in real time[2].

It is important to note that independent corrections are made to the data from each individual satellite, therefore the reference and mobile stations must see the same constellation of satellites. Any satellite not seen by both stations cannot be included in a DGPS calculation.

The DGPS method of fig. 1 requires a continuous supply of corrections data in real time from the reference station. If the corrections are interrupted for more than 20-30 seconds, the moving GPS receiver reverts to standard GPS accuracy, and DGPS-accurate results cannot be calculated at a later time.

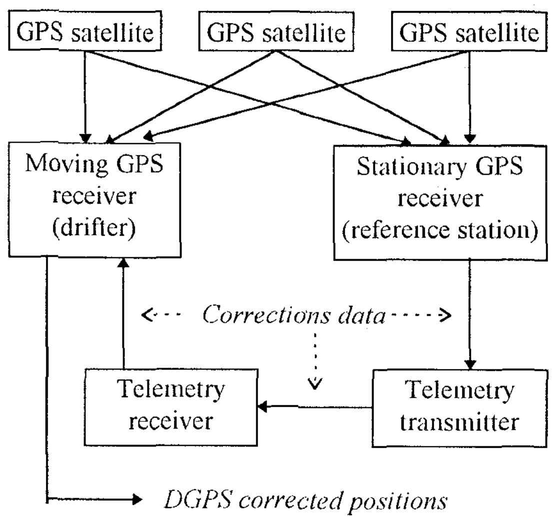

Fig. 1. Conventional (real-time) DGPS system.

The need for continuous real time telemetry of corrections data presents significant logistical problems for drifter applications. A source of corrections must be available. Real-time DGPS corrections are available in some coastal areas of the USA using radio beacons maintained by the US Coast Guard, and in selected US metropolitan regions on subcarrier channels of commercial broadcast FM radio stations. While the availability of commercial and governmental corrections sources is expected to grow, their coverage is by no means continuous within the USA and scant to absent outside the country. In the absence of commercial sources, the end user must obtain and maintain their own reference station and telemetry transmitter.

A telemetry receiver must be present in each drifter. This adds cost and subtracts from the power budget. Receivers for the commercial and governmental broadcast services mentioned above are designed for the marine and vehicle markets. Their size and power requirements do not lend themselves well to use on drifters. For example, the Coast Guard beacon system operates around 275 KHz. This frequency range requires a 2 meter or longer whip antenna on the receiver that would add considerable windage to a small drifter.

Finally, a reliable telemetry link must be maintained during operations. This is perhaps the greatest constraint. A small drifter, low in the water and operating with reasonable telemetry power (2 watts VHF) can be expected to have telemetry ranges under ideal conditions of perhaps 10 km to a surface base station. Rough seas or intervening headlands can cut this range considerably. When telemetry is used intermittently to check drifter function or change an operating parameter, range limitations are usually not a major constraint. Requiring the drifter to make a telemetry link for each and every record is a much greater challenge.

II. Wide Area Differential GPS

An alternative way of obtaining DGPS drifter data is shown in fig. 2. This method is termed Wide Area Differential GPS (WADGPS)[3]. Rather than rely on real time telemetry of GPS correction data, WADGPS uses postprocessing to remove the effects of SA from GPS data.

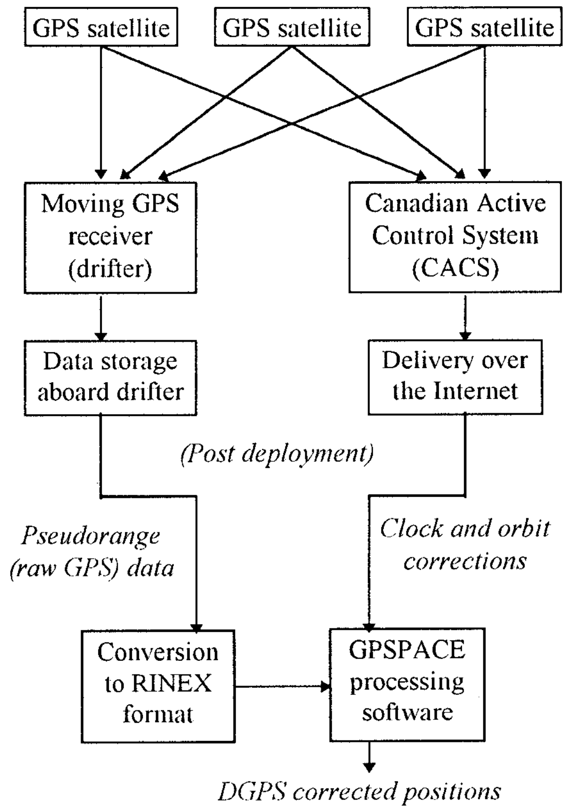

Fig. 2. Wide Area (postprocessed) DGPS system.

When using WADGPS, the mobile platform stores the raw GPS data received from each satellite. The raw data (called pseudoranges) are approximately 10 times the size of the calculated GPS positions, so telemetering them directly from the drifter is not practical. Instead, the pseudorange data are stored within the drifter, and standard GPS positions sufficient for logistical purposes are sent out in the telemetry stream.

The Geodetic Survey Division (GSD) of the Government of Canada has established the Canadian Active Control System (CACS) to provide support to high precision geodetic surveys[4]. CACS currently operates approximately 12 high precision GPS tracking stations within Canada, and has access to the data from about 60 additional stations worldwide operated by members of the international GPS Service for Geodynamics (IGS). Using the data from these tracking stations, CACS generates the satellite clock and orbit corrections needed to remove the effects of SA from GPS data. CACS correction data is generally superior to that generated by a user-maintained local reference station for two reasons. First, the quality of the reference station equipment used by IGS is far higher than can be afforded by most end users. Secondly, CACS generates corrections for all satellites everywhere, so there is never an issue of some satellites not being in view of both the mobile and reference receivers.

CACS corrections are available over the Internet a few days after real time. Costs are $30/day for Canadian data and $60/day for global data. Note that Canadian data is valid for approximately 500 miles beyond the national boundary of Canada, so operations in the northeast and northwest US and Alaska can use the more economical Canadian data. If free orbit corrections supplied by the US Coast Guard are used (available at http://www.navcen.uscg.mil) the price of using CACS clock correction data only drops to $15/day for Canadian data and $45/day for global data.

After retrieval of the drifter, the raw pseudorange data is downloaded from internal data storage to a desktop computer. It is then converted to a standard format known as RINEX for Receiver Independent EXchange Format [5]. RINEX is a standard format for storing GPS data supported by many manufacturers of GPS hardware and software.

Finally, the RINEX format drifter data and the CACS correction data is processed on a personal computer using the program GPSPACE. GPSPACE is written and supported by the same Canadian GSD that operates the CACS, and sells for $130. Output from GPSPACE is DGPS-quality positions.

WADGPS has several features to recommend it for drifter use. The main hardware requirements are a GPS receiver capable of output of pseudorange data and sufficient data memory space to store the raw data. The need for real time telemetry is eliminated, along with the attendant expense and logistical problems. On balance, WADGPS appears to be far superior to real-time DGPS for most drifter applications.

III. Modification of a Drifter To Use WADGPS

The Brightwaters Model 104 drifter is an autonomous GPS drifter with internal data storage. Depending on the options chosen, data can be telemetered using ARGOS or VHF packet radio or both[6,7]. Four Model 104 AV (ARGOS and VHF telemetry) drifters owned by the College of Oceanic and Atmospheric Sciences of Oregon State University were refitted to use WADGPS. Only minor changes in three areas were needed to accomplish the upgrade.

A. GPS receiver.

The GPS receiver currently used in the Model 104 is the Motorola Oncore. Firmware to allow pseudorange output is available on this GPS at an extra charge that until recently nearly doubled the cost of the receiver. This additional cost is purely a marketing decision, since pseudoranges are generated in all GPS receivers, and enabling their output is merely a matter of a few lines of code. Fortunately, market forces have apparently encouraged Motorola to recently lower the charge for the pseudorange option. Hopefully, this trend will continue until pseudorange output is available for little or no additional cost.

B. Data storage.

Model 104 drifters manufactured before 1996 have 28K of CMOS RAM data storage included. While sufficient for storage of standard GPS data, this amount of memory would be inadequate for storage of the much larger pseudorange data set. Additional memory cards was installed in the OSU drifters to add 128K of memory, sufficient to store pseudoranges for 1000-2000 positions.

Beginning in January 1996, Model 104 drifters have 256K RAM standard, of which over 200K is available for data storage. This memory capacity should be sufficient for most WADGPS applications.

C. Firmware and software.

The firmware was changed as little as possible to retain compatibility with existing 104 drifters.

At the conclusion of a standard GPS acquisition cycle, the central microcontroller sends a series of commands to the GPS to collect a set of pseudorange data. The pseudoranges are stored in a binary compressed format in a separate section of memory from the standard GPS positions and auxiliary sensor data. When desired, a command to the drifter offloads the pseudorange data to a desktop computer using XMODEM protocol. A utility program then is run to convert the binary compressed pseudorange data to standard RINEX format for postprocessing.

IV. Results

A test of WADGPS was conducted using a stationary receiver recording positions at a 2 second interval for approximately 1 hour. Fig. 3 is the uncorrected data, which shows the non-random wandering characteristic of SA. The 2-dimensional rms deviation from the mean position of the data is 33.5 meters. Fig. 4 is the same data after WADGPS processing. The data is clearly more randomly distributed, and the 2D rms deviation from the mean position is 9.3 meters, an improvement of 72% compared with uncorrected data.

Currently the WADGPS-modified Model 104 drifters are being readied for a full field test in Crater Lake, Oregon. It is expected that additional familiarity with the WADGPS correction method and refinements to the processing will produce even more accurate results in future work.

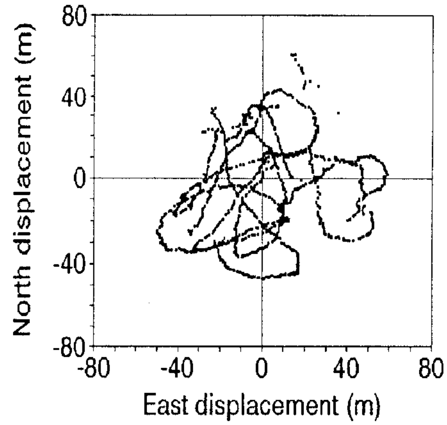

Fig. 3. Uncorrected GPS data.

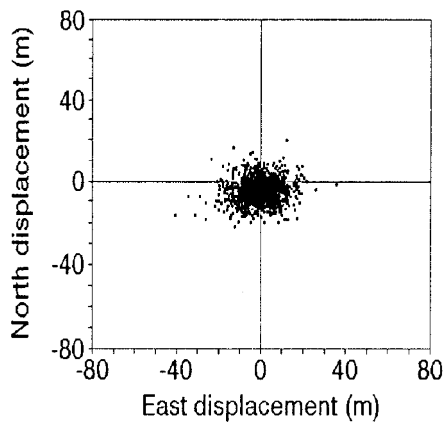

Fig. 4. WADGPS-corrected data.

Acknowledgments

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