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1298

Results of Real-Time Testing & Demonstration of the U.S. Army Corps of Engineers Real-Time On-The-Fly Positioning System

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ABSTRACT

The U. S. Army Corps of Engineers has been developing a GPS carrier phase based positioning system for hydrographic surveying and dredging since 1988. This system provides real-time three dimensional positions with horizontal and vertical accuracies better than one decimeter over ranges up to 20 kilometers from a single reference station without static initialization. The project has passed from concept development through feasibility studies, system analysis, resolution of carrier ambiguities on-the-fly (OTF), to final system integration. The real-time testing of the system began in March of 1993 and public demonstrations of the system began in October, 1993. Testing of the system has been performed under varying operating conditions to evaluate the limits of OTF ambiguity resolution for precisely positioning moving platforms. Tests have shown that this system is capable of 1-3 centimeters in all three dimensions. This paper will summarize the results of the testing to date and briefly describe the OTF system.

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) is responsible for keeping the waterways of the United States navigable. Recognizing the need for and potential benefit of a more accurate positioning system for its hydrographic surveying and dredging mission, the Corps embarked on an ambitious research program to develop a prototype positioning system based on Global Positioning System (GPS) carrier signals. This prototype system is designed to deliver, in real time, three dimensional positions with subdecimeter accuracies, for ranges up to 20 kilometers (km) using a single reference station. The development of the On-The-Fly (OTF) prototype system was initiated by the U.S. Army Topographic Engineering Center (TEC) in 1988 and funded under the Dredging Research Program of the USACE.

The need for such a system by the Corps initially arose out of its ongoing dredging mission. Several millions of dollars are spent each year by the Corps in the maintenance of the waterways of the United States. The Corps conducts *Condition Surveys* on a routine basis to identify channel obstructions. If dredging is required to clear the channel obstruction, the Corps often contracts this work out. If the work is contracted out, a typical scenario is for the Corps to perform a hydrographic survey before the work is done to identify to the contractor the specific material to be removed. After the work is completed, the Corps performs a *Contract Payment* survey. The current horizontal accuracy standard used for a Contract Payment survey is 3 meters (m) 1DRMS, although there has been discussion to tighten this requirement to 3 m 2DRMS. The majority of the positioning systems used today by the Corps are range-range or range-azimuth systems. Most of these systems require daily calibration or initialization at a site local to the job. In addition, occupation of other previously surveyed shore stations are necessary for each day of the survey.

Survey and dredging operations must also be referenced to a vertical datum. Tidal, river or lake gages are used to establish readings upon which a vertical datum such as mean lower low water (MLLW) is established. The surveyor must determine the differences in elevation from the established datum using such methods as a zoning model, limiting the accuracy typically to 0.2 m. Final payment is made to the contractor when both the contractor and the Corps agree that the identified material was removed and on the volume of the removed material. The prototype system developed by the Corps provides subdecimeter accuracies in three dimensions in real-time. Using a positioning system that is accepted as definitively accurate can decrease the dispute over costs which arise from disagreements on the actual amount of dredged material removed. Additional savings are realized on a per job basis due to the fewer personnel and decreased number of shore stations; only a single shore station is necessary and daily calibration is not necessary. It is anticipated that the implementation of this system throughout the Corps will save the government and its taxpayers millions of dollars.

Development of the system has progressed in three primary phases which have been well documented in previous papers (DeLoach and Remondi, 1991; DeLoach, Frodge and Remondi, 1993; Frodge et al, 1993). The project has gone through a full development cycle from conceptual level to the development of a working prototype. Feasibility studies, system analysis, extensive testing strategies, and considerable research with regard to the resolution of carrier ambiguities 'on-the-fly' were some of the major program activities. The development and testing of the prototype system is now complete and demonstrations have been ongoing since August, 1993. Currently, the project is in its sixth year of the planned six year effort. The goal of this last year of this specific effort has been to demonstrate the OTF capability to the Corps districts, further refine the OTF software and fully determine the operational environments under which it is most effective. To date, the OTF system has been demonstrated, undergone testing and has been used as a production level engineering system. The results and findings of these applications shall be discussed within this paper.

DESCRIPTION OF THE OTF SYSTEM

The real-time OTF prototype delivers high precision kinematic positioning accurate to less than 5 cm at the antenna phase center, while simultaneously providing a separate output for meter level differential GPS (DGPS) for navigation purposes. A block diagram of the system is shown in Figure 1. The system performs on-the-fly carrier phase ambiguity resolution.

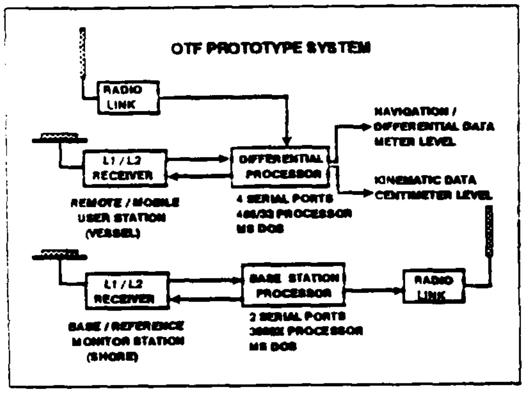

Figure 1. Block Diagram of the OTF Prototype System

As a design constraint, the OTF system was developed using only equipment that could be purchased off-the-shelf. The OTF software is the heart of the system and was the focus of much of the development effort. The software was designed to require minimum operator attention and has had several quality control procedures built-in to assure that the high performance and reliability of the system is maintained. The system consists of setups at the reference and remote stations and a data link as shown schematically in Figure 1. Dual frequency (L1/L2) GPS receivers are required at both the reference (Monitor) and remote (User) stations. Shipping the raw data from the reference station allows a single 386 SX Personal Computer (PC) to carry out the reference station functions. These functions include setting the GPS receiver to output the required data, translating that data to the desired format and transferring the formatted data to the data link for transmission. Additionally, the reference station package is capable of recording data if the operator requests it. Although the prototype has been developed and built utilizing 486 computers and Trimble 4000 SSE receivers, it is hoped that in the near future other platforms and receiver types will be interfaced to use the OTF software.

The high precision kinematic OTF (KOTF) mode positioning is available from the system once integer ambiguities are resolved by the software. As long as the system remains in the KOTF mode, real-time subdecimeter positioning in 3 dimensions is available at the (mobile) user site. To remain in this KOTF mode requires both reference station data and a maintenance of lock on at least four satellites. If that number drops to below four, the ambiguities will again be resolved after the system reacquires lock on a sufficient number of satellites. The software is 'smart' software and will automatically detect the need to reinitialize. The software will also trigger reinitialization if quality factors based upon residuals fail to meet certain predefined limits. Note that the system is still capable of meter level DGPS navigation even if loss of lock occurs and will provide this function for a limited time even without data from the reference station.

The system uses L1/L2 carrier phase and C/A code ranges for ambiguity resolution, although L2 codeless code ranges and P code ranges may also be used. The system has been designed not to rely on the continuity of L2 carrier phase, since only the fractional phase part of the L2 carrier measurements is used. After ambiguities are resolved, only the L1 carrier ranges are required to maintain the high precision KOTF positioning. However, ionospherically-free dual frequency kinematic GPS was also developed. Note that the Interface Control Document 200 (ICD 200) parameters are required by the system not only at startup of the software, but whenever the GPS satellite constellation changes or an ephemeris update occurs. Figure 2 depicts the general flow of required GPS data. The meter level DGPS process uses primarily C/A code and L1 carrier ranges.

The current prototype has been developed on the premise that all required raw GPS observations, i.e. the GPS time tag, L1/L2 carrier phase, and L1 code, are transmitted from the reference station and the actual computations necessary for KOTF and code DGPS take place at the remote/user station. The KOTF process requires time-matched reference and remote station data. In the code differential process, extrapolated reference station differential corrections are applied to the current remote station observations, as is done in standard DGPS systems. The difference is, however, that these corrections with their rates are generated at the remote site from the raw data that was received from the reference station data. The system can be interfaced with any other system requiring this level of accuracy in positioning using the interface string (See Appendix 1). This string was designed to be as close as possible to the existing National Maritime Electronics Association (NMEA) GPS string formats. The system works in a robust and reliable manner out to the design goal range of 20 km in real-time, although the range limit is greater. Future testing this year will determine more exactly what the range of the system is.

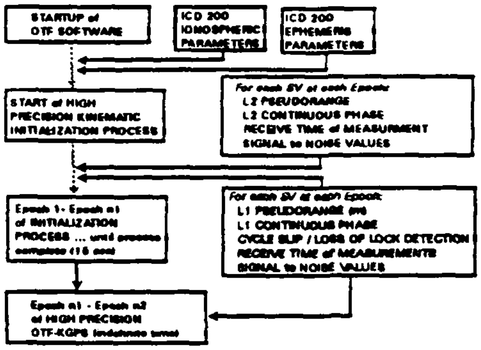

Figure 2. Schematic of the information flow required by the OTF system.

The system requires a data link capable of a minimum of 4800 baud. The system has been tested using 9600 Baud Dataradio UHF sets (460 MHz) that can operate at line-of-sight distances up to 25 km, depending upon antenna height and power used. Tests have also been run using 1 watt spread spectrum units. Spread spectrum sets have the advantage of not requiring a Federal Communication Commission (FCC) license, but provide a more limited range of possibly 10 km (line-of-sight, rather ideal conditions). Within the tests run, the effective range obtained, without using any repeaters, was 8.1-8.5 km. VHF sets recently acquired have been used with the system testing and have provided a disappointing 8-9 km. Successful tests were run out to 18.6 km using the UHF sets. Further testing is planned.

The remote/user station uses a single 486 DX/33 PC. At the user station, the reference and remote station data are combined to accurately determine the remote station position. The remote station software, in its typical mode of operation, provides navigation and KOTF output at a 1 Hz rate. OTF ambiguity resolution computational time is usually ≤ 1 second. When used operationally or demonstrated, the initialization time interval is set to 15 seconds, although OTF initialization has been achieved in 1 second (two epochs). This equates to instantaneous initialization. The system is reliable and easy to use.

THEORETICAL BASIS for KINEMATIC ON-THE-FLY GPS

The development of the algorithms necessary for high precision kinematic On-The-Fly GPS (KOTF GPS) began in late 1989 and can be traced through a number of papers (Remondi 1991; Remondi 1992a; Remondi 1992b). Initialization is performed in three steps: First, a meter level first guess is acquired. Second, a search grid is established; and, third, the grid 'candidates' are evaluated to isolate the correct grid point. In fact, there are many variants and the following approach is both representative and simple to describe.

Step 1: Meter Level Positional Boundary.

The initial estimate of receiver's position is from the code range measurements. This equation is:

$$R_{bu}^{jk} = \rho_{bu}^{jk} + \epsilon_R,\ j = j_1, j_2, \ldots j_n$$

Where:

R : is the code range measurement;
ρ : is the range model in meters;
ϵ_R : is the unmodeled part;
b : is the base or reference receiver;
u : represents the user receiver;
k : represents the reference satellite;
j : represents the other satellites needed to form the double difference.

It is assumed that there are at least three other satellites, but most of the time there will be four to six other satellites (ie $j = j_1, j_2, \ldots j_n$, where $n=4, 5$, or 6). Although this system of equations can be solved for the position of user receiver (ie $\rho = \rho(x_u, y_u, z_u)$), better results are achieved by smoothing the code ranges with carrier range measurements. The carrier range equation is:

$$\lambda \left[\phi_{bu}^{jk} + N_{bu}^{jk} \right] = \rho_{bu}^{jk} + \epsilon_\phi$$

Where:

λ : is the wavelength of the carrier signal (meters per cycle);
ϕ : is the carrier phase measurement (cycles);
N : is the unknown carrier phase integer ambiguity (cycles); and ,
ϵ_ϕ : is the unmodeled part of the carrier (meters)

The same range model ρ is in both equations. Since N is a constant bias, N will drop out of a time difference, leaving the following:

$$R_{bu}^{jk}(t_\phi) = R_{bu}^{jk}(t_i) - \lambda \left[\phi_{bu}^{jk}\lambda(t_i) - \phi_{bu}^{jk}\lambda(t_\phi) \right] + \epsilon_{\phi R}$$

Simply put, code range measurements at any subsequent epoch, t_i, can be mapped to the reference time (epoch), t_ϕ. This provides a large number of different measurements of $R_{bu}^{jk}(t_\phi)$ which can be averaged. Finally, placing these averaged ranges into the initial code range equations allows the x_u, y_u, z_u to be determined at the meter level. The search grid of step two is defined about this initial positional estimate. The better the initial positional estimate is determined, the smaller the search volume can be. This equates to a faster overall initialization time since many otherwise attractive candidates will be eliminated due to the fact that they fall outside the boundaries of the search volume. Stated another way, the smaller search volume leads to faster computational times since fewer candidates need to be considered.

Step 2: Forming the Search Grid.

There are many ways to form the search grid. An efficient way and one easy to explain is based on the intersection of three double difference planes from a given set of four satellites. Dr. Remondi has implemented two other search schemes not presented here. By selecting four satellites each of which is not too low in elevation and which together provide a favorable Positional Dilution of Precision (PDOP), the real values of carrier phase ambiguities can be compared at the initial positional estimate and rounded to closest integers. Placing these determined integers each into the carrier phase equations for that specific set of those four grid satellites, provides a single grid point. Neighboring grid points can be computed by incrementing any one of the integer ambiguities by unity. Having found three orthogonal neighboring grid points, one can compute others within predefined neighboring volumes by vector addition. Significant efficiencies can be achieved by performing this procedure for both L1 and L2, although in principle one can do it for just L1. The points of each grid are formed as the intersection of three double difference planes and thus the grids are actually a lattice of three dimensional positions. There will only be a finite number of three dimensional points that will appear in close proximity to each other to be considered intersection points of the L1 and L2 grids, identified through the process outlined above. These remaining grid candidates can be evaluated to determine which is truly the correct candidate. Typically, if there are 30,000 initial points on each of the L1 and L2 grids, for a total of 60,000 points, somewhere around 500 candidates will remain to be processed by the following step, described below.

Step 3. Evaluating the Candidates.

The remaining candidates must now be evaluated. This is the final step of the KOTF initialization process. For a test grid candidate one uses the carrier phase equations to determine the integer ambiguities for all double differences. This permits a computation of the modeled range, ρ, and ultimately provides a residual. The correct grid candidate will have small residuals whereas the others will not. Should multiple grid candidates have similar small residuals, lane resolution may not be possible. The statistics calculated will indicate clearly if a correct candidate has been found, indicating that the correct solution for the integers has been resolved. If the resolution is uncertain at the reference time, t_ϕ, one can continue the process in subsequent epochs t_i until a single lane emerges as clearly the correct candidate.

Within the OTF software, the time interval for this process is user selectable. As mentioned, this time is currently set at 15 seconds, although several of the tests over the summer were run using a 30 second time interval. The data is first analyzed in a forward manner, from epoch t_ϕ forward in time towards epoch t_n. If the OTF system's software cannot resolve the integers, then the software automatically will begin the initialization process again, processing the same data backwards in time, beginning with epochs t_n and proceeding backwards towards t_ϕ. Although the initial 15 seconds is normally sufficient, if additional time segments are required, initialization may not require the entire set of epochs back to t_ϕ, ie initialization will take greater than 15 seconds, but less than 30. The software will indicate if initialization was obtained on the forward or backward pass. During the demonstrations, there were some rare cases where obstructions coupled with poorer GPS constellation PDOP and geometry relative between the satellites and the survey vessel caused initialization to require more than two passes. Note, however, that initialization still occurred in less than one minute (within the fourth pass). Once the system is initialized, the display will change to reflect that in addition to the DGPS data, the KOTF high precision positional data is now available. The statistics for the resultant top five candidates is shown on the screen.

RESULTS FROM THE REAL TIME TESTING

Real time testing was broken into stages that progressed from static baseline tests to land mobile tests and, finally, to tests in an operational environment aboard a survey vessel. The static tests began in March of 1993. They determined that the system performed well over the full variation of GPS visibility and conditions. Typically, positions were obtained 98% of the time (23.5 hrs/day). The remaining 2% of the time integers could not be established due to poor satellite constellations containing several low elevation satellites or not enough satellites. Results from monitoring the system over the static baselines for months of 24 hour periods show that the system is very quiet. Typical values are standard deviations of 3-4 millimeters in latitude and longitude (maximum variance 10-20 mm) and 10 mm in height (maximum variance 50 mm).

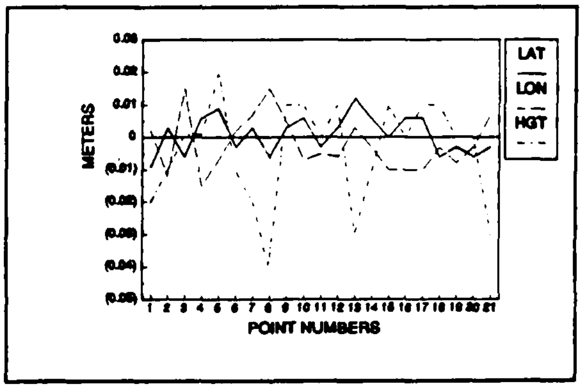

Figure 3. Kinematic Land Test Results.

The usual setup for any land mobile test or demonstration entailed setting up a truck or cart as the mobile remote user and then navigating the user system to positions previously established using static GPS methods. Several truck tests of this type have been run over ranges from the reference station to the mobile remote varying from ≤1 km up to 19.5 km. Both the short and long range tests produced similar results for accuracy and repeatability. Horizontal positions checked within 1-2 cm and the vertical positions were within 1-3 cm. This type of test involves some stationary occupations of the point; these times were kept to a minimum -- almost always less than one minute. The system was also closely observed while en route between stations, with driving speeds varying 8-40 kph (5-25 mph) and its performance was found to be very satisfactory. Figure 3 shows some typical results from a truck test run near the JECA facilities in Louisiana.

The next step was to move the system onto a survey vessel. Initial tests were run in the vicinity of Norfolk, Virginia, in August, 1993. For these tests, the OTF reference station was installed atop the USACE Norfolk District office building and the remote/user equipment was installed on the Survey Vessel (S.V.) *Adams*. These tests compared the real-time vertical positions obtained over time using the OTF system with tide gage readings to determine vertical accuracy relative to tidal movement of the vessel. Additionally, recordings were made using a spirit level as another independent check. For these tests, the *Adams* was tied to the dock for a full tidal swing of 8 hours. OTF positional data were logged on disk and also recorded with the tide gage data, measuring to a point on the *Adams*. The distance between the *Adams* and the reference station was 290 m for one test and 1900 m for the other.

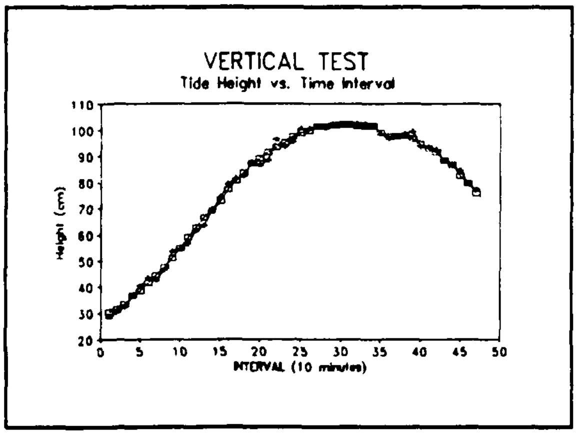

Figure 4 Vertical test results.
NOS Tide Gage (□); GPS a (+).

Table 1 summarizes the results from tests run to determine the vertical accuracy of the system. The comparison between the two sets was better over the longer baseline, perhaps a bit surprising. It is thought that this can be attributed to fewer problems arising from boat traffic during the longer baseline test. Figure 4 shows a detailed plot of the data from the longer baseline test. Field notes show that the passing boat traffic coincides with the larger variations that can be seen on the graph, for example at approximately 220 minutes and 390 minutes. The interested reader is referred to the previous paper (Frodge et al, 1993b) for more detailed descriptions of any of the above tests and results.

COMPARED	STANDARD DEVIATION (290 m)	STANDARD DEVIATION (1900 m)
GPS vs LEVEL	1.9 cm (0.061 ft)	1.5 cm (0.049 ft)
GPS vs GAGE	1.4 cm (0.045 ft)	1.6 cm (0.051 ft)
LEVEL vs GAGE	1.3 cm (0.042 ft)	0.9 cm (0.029 ft)

Table 1 Results from the vertical comparison tests.

One of the most important advantages of this system for many users is the increased accuracy in the vertical component. During a breakwater survey conducted by JECA in California, the data illustrated in Figure 5 was collected. This data compares data collected with a heave compensator at 10 Hz and the vertical data provided by the OTF system at 1 Hz. Due to the differences in rates, the OTF was extrapolated between the data points. The two sets of data compare remarkably well.

Several test/demonstrations of the OTF have occurred since September. The first demonstration took place in early October, 1993, in Wilmington, North Carolina. This demonstration took place in the downtown area and just south of Wilmington on the Cape Fear river. The site was selected to maximize performance of the range-range system that is normally used onboard the Wilmington District's S.V. *Gillette*. The *Gillette* ran several longitudinal and cross section lines. Running these lines took the vessel underneath a bridge twice, once on the way down to the survey area and again on the return trip.

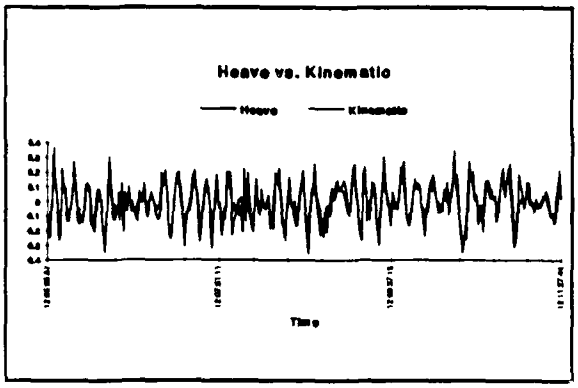

Figure 5. KOTF data compared to heave compensator data, time vs meters.

The OTF system was used as positioning input to the HYDRO navigation system that was brought onboard the *Gillette* for the demonstration. The *Gillette* uses HYPACK as its normal system. The HYPACK system used a Del Norte range-range system as its input for positioning. Both systems were hooked into the same fathometer. This part of the demonstration was to show that the OTF system could be used as comparable systems that the districts already have in operation. Data was saved for later analysis, as well. This analysis will focus on the vertical performances. . The demonstration onboard the *Gillette* also showed how the OTF system performed in an operational environment, for example, automatically reinitializing after experiencing obstructions, such as the Wilmington bridge. As mentioned before, the system usually initialized within 15 seconds, although there were occasions where multiple initialization time intervals were required. To demonstrate the specific capabilities of the OTF system, a cart test was run onshore. Changes adding the forward and backward processing method described earlier were made in the software between the Wilmington demonstration and the next demonstration in Astoria, Oregon, to improve the initialization time.

The demonstration in Astoria took place in mid-November. The general format for the demonstration was the same as that in Wilmington. The OTF system was set up on the Portland District's S.V. *Hickson*. The demonstration site again was selected such that the vessel would have to transit underneath a bridge twice during each demonstration. The shore demonstration used a truck set up. No significant problems were experienced with the OTF system. The worst case experienced was that the OTF system lost lock and did not reinitialize until within the fourth pass. Note that this still took less than one minute, since each pass is at a maximum 15 seconds. The typical case was that one 15 second pass was required and the system initialized in the forward manner on that first pass. There were, notably, several occasions where the *Hickson* passed under the bridge and the system maintained uninterrupted operation at both the meter and subdecimeter level. This situation did not occur in Wilmington, probably since the bridge at Wilmington was lower and some improvements to the software between the Wilmington demonstration and the Astoria demonstration increased the robustness of the system.

Other tests are planned or ongoing that utilize the OTF system. TEC is an experimenter with NASA's Advanced Communications Technology Satellite (ACTS) (Austin and Frodge, 1993). NASA set the ACTS into position during the recent space shuttle mission. For a two week period in December, a static DGPS baseline experiment was run using ACTS as the data link. The baseline length was approximately 320 km. The ACTS was used to provide a real time data link over that baseline for static DGPS. Although significantly faster rates can be supported by ACTS, a 2 second update rate was used for these experiments. Meter level DGPS ran over the link with no apparent problems. Although it was not expected that the OTF system would even initialize, it did several times and held the KOTF solution for several periods of ½ hour or more. Detailed analysis on the data has not yet occurred to determine if these were indeed the correct integers, but even that initialization occurred is intriguing.

During December, 1992, an extensive survey was conducted over long baselines stretching over several states using NovAtel cards (Cannon et al, 1994). Some of the analysis of this data has focused on resolving the problems of the ionosphere over such long baselines. TEC is hoping to receive funding to double or triple the range of the OTF system to 40-60 km. The kind of results obtained from the analysis of the NovAtel survey and the ACTS experiment are some of the groundwork being done to prepare for that effort. Actually, we are confident that the range can be extended to at least that as stated above. The significant limiting factor for use of the system would then be the data link. The interested reader is referred to an upcoming report on some of the results of the NovAtel survey that will be presented during the upcoming IEEE PLANS'94 conference.

The OTF system has been used on production level jobs by JECA. In addition to the breakwater survey during which the data shown in Figure 5 was collected, it has also been used to position over 8,000 points in less than 3 weeks for a land survey project (Lapucha et al, 1994). The interested reader is again referred to a paper at PLANS'94 on those efforts.

Many tests and demonstrations have occurred. The results from these tests will be made available as soon as they are ready. It is hoped that quite a few of the results will be ready in time to incorporate into the paper to be presented at the 20th Congress of the International Federation of Surveyors (FIG) to be held this March in Australia.

FUTURE TESTING

Additional tests that are being planned include demonstrating the OTF system onboard a dredge in both the open waters of the ocean as well as in a busy harbor area. In late March, it is anticipated that a test will occur onboard the USACE dredge *Essayons* in ocean waters that provide 7-15 foot swells. Since the work done by the *Essayons* is in the shipping lanes, vessel traffic will be evident. Additionally, the dredge will be working in the Richmond Harbor area , providing another realistic operational environment within which to determine the operational limits and constraints of the OTF system. It is also hoped that by the end of April, 1994, the system can be placed onboard a survey vessel working in a somewhat higher sea state, such as that provided by the mouth of the Columbia River.

Plans also include using the OTF system as positioning for autonomous land vehicle (ALV). The ALV has already been tested at speeds up to 55 mph on the open interstate with no operator intervention, as evident in a graduate student's impressions recorded on video camera to verify that the vehicle operated without human assistance, ie robotically. These types of systems can be used in a variety of applications. This type of work is moving towards systems necessary for the development of the Intelligent Vehicle Highway System, as well as for site clean up of ordinance or in areas that are for whatever reason not deemed safe for humans. Other work in the area of robotics is planned, as well as some potential work in the area of deformation monitoring of large engineering structures. Additionally, an ongoing project is working towards applying the OTF technology towards real-time determination of tides. Data will be collected over a six week period this summer in the Bay of Fundy.

CONCLUSIONS

Centimeter level accuracy in real-time is a reality. The tests have convinced us that this technology will have a great impact on both surveying and navigation. This particular system is robust, reliable and easy to use and has surpassed its original design goal specifications. The tests have shown that real-time tide corrections using OTF are possible; this is very important for the dredging industry. Although this system is referred to as a 'prototype' and will be further developed, it has far exceeded the original design specifications and can be used today as a reliable working system for applications that require real-time centimeter horizontal positioning, for example, breakwater surveys. It is also a valuable engineering tool for those operations for which post-processed data will suffice. In reality, we have demonstrated that real time OTF is as easy to provide as DGPS within the current range limitations.

DISCLAIMER

Mention of a commercial company or product does not constitute an endorsement by the National Oceanic and Atmospheric Administration or the U.S. Army Corps of Engineers. Use for publicity or advertisement purposes of information from this publication concerning proprietary products or the test of such products is not authorized.

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APPENDIX 1

INTERFACE STRING
OTF OUTPUT DATA FORMAT / KINEMATIC & DIFFERENTIAL

General Information:
This output string format was developed for this project. It is a NMEA-like string, so that manufacturers can easily interface to it. An example string is:
$RTGGK,HHMMSS.SS,MMDDYY,DDMM.MMMMMM,N,DDDMM.MMMMMM,W,Q,UU,DD.D,EHT.XXX,M*HH <CRLF>

Where the fields are comma delineated and represent:

$RTGGK	**$RT** is in place of the **$GP** NMEA designator for GPS **GGK** is NMEA-like for lat, lon, and kinematic
HHMMSS.SS	UTC TIME of POSITION FIX (e.g. 102933.00)
MMDDYY	UTC DATE of FIX in month, day, year format (e.g. 052493)
DDMM.MMMMMM	Latitude of FIX in degrees and decimal minutes to 6 places (e.g. 3013.123456)
N	Latitude N or S (e.g. 3013.123456,N)
DDDMM.MMMMMM	Longitude of FIX in degrees and decimal minutes to 6 places (e.g. 09203.123456)
W	Longitude E or W (e.g. 09203.123456,W)
Q	GPS *Q*UALITY INDICATOR 0 : FIX not available or invalid (not used) 1 : Non-differential GPS FIX (not used) 2 : Differential FIX 3 : Kinematic FIX (e.g. 3)
UU	Number of SATELLITES IN SOLUTION (e.g. 07)
DD.D	DILUTION OF PRECISION (DOP) of FIX (e.g. 01.3)
EHT.XXX,M	ANTENNA ELLIPSOIDAL HEIGHT *(not MSL)* in meters (M)
***HH**	CHECKSUM (e.g. *FB)
<CRLF>	CARRIAGE RETURN-LINE FEED CHARACTERS

The length will change depending on the ellipsoid height value. The maximum length of a NMEA string is 80 characters. Differences from NMEA GGA format:

1. Ellipsoidal height not antenna altitude (msl/geoid)
2. Geoidal separation not output
3. No age of correction or differential station number
4. Date of fix output