INTEGRATED SATELLITE RECEIVER NAVIGATION SYSTEM FOR SURVEY SHIPS

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ABSTRACT

A Satellite Receiver Navigation System (SRNS) was developed to provide precise navigation data to bathymetric survey ships operating in broad ocean areas. Operation of survey ships in deep ocean areas not having LORAN C coverage resulted in the necessity to develop and integrate a satellite positioning system to alleviate position and velocity degradation arising from infrequent TRANSIT fixes. The resulting system tracks both TRANSIT and GPS satellites, computes positions, performs real time determination of data validity and distributes valid satellite information to the navigation system for use in determining best present position. Computer monitoring of receiver performance, as well as, integration with an on board cesium beam standard, permits extended use of GPS navigation data beyond that for typical shipboard applications.

The new system, has been installed and integrated with other shipboard navigation equipment on board four survey ships. The SRNS has improved the performance of the overall survey ship navigation system in ocean areas lacking LORAN C coverage. The SRNS includes a feature whereby GPS satellite coverage is extended by approximately two hours a day through the use of a two satellite navigation mode.

INTRODUCTION

This paper describes the development of a Satellite Receiver Navigation System (SRNS) to provide precise navigation data to bathymetric survey ships operating in broad ocean areas. These survey ships are operated by the Naval Oceanographic Office (NAVOCEANO).

The ship’s survey system, shown in figure 1, are integrated combinations of navigation and sonar equipments, tailored to meet the unique mission requirements. Geodetic positions are derived from Loran C and navigation satellite signals. Reduction of Loran C noise is accomplished by using a Miniature Ships Inertial Navigation System (MINISINS) for smoothing. The MINISINS provides velocity data, ship’s position between satellite fixes, and furnishes precise attitude data for use by the sonar array. The multi-beam sonar is capable of obtaining simultaneous depth soundings from a swath width of deep ocean bottom terrain. The shipboard computer system combines the navigation and sonar data to plot bathymetric contours in real time.

Operation of these vessels in deep ocean areas not having Loran C coverage resulted in the reliance on MINISINS for navigation data. The proper performance of the MINISINS under these conditions could only be maintained by using infrequent TRANSIT satellite position fixes to predict and correct errors.

In June 1985, NAVOCEANO tasked the Naval Air Development Center (NAVAIRDEVCEN) to develop a satellite receiver system, integrated with the ship’s survey system, to support MINISINS operation using position fixes derived from existing TRANSIT and GPS satellites. This system was intended to provide an interim capability until the DOD GPS Phase III User Equipment was available for installation on the survey vessels. Unfortunately at this point in time, the TRANSIT receiver existing on the ships had reached obsolescence and the GPS DOD User Equipment program was just entering the production stage (Phase III).

The options considered to meet the requirements included:

1) Replacing the aging TRANSIT receivers with state-of-the-art receivers and adding a stand alone GPS receiver (either a laboratory set, a Phase II UE set, or a commercially available set).

2) Specifying/procuring a combined TRANSIT/GPS Satellite Navigation Receiver System to meet specific system requirements.

The approach taken was to purchase "off-the-shelf" TRANSIT receivers and lease optional GPS upgrade kits until the GPS Phase III would be available. The receivers were modified to meet specific integration requirements and interfaced with shipboard computers to form the Satellite Receiver Navigation System (SRNS).
SYSTEM INTEGRATION

System Configuration

The integrated system consists of two satellite receivers interfaced to a shipboard computer, selected heading sensor, and the onboard velocity processing and time and frequency systems. Each receiver tracks, decodes, and processes TRANSIT and GPS satellite signals to compute, display and output navigation data. The receivers have a 2 channel TRANSIT capability and provide GPS positions with as few as two satellites in view.

Each receiver communicates with the satellite computer over an RS232 serial interface to provide TRANSIT and GPS navigation data, satellite prediction information and unprocessed TRANSIT data. The Computer provides ships velocity for use in determining TRANSIT position fixes and dead reckoning (DR). Additional interface options include: output of unprocessed GPS data, input of fine grid geoidal height data and computer controlled satellite selection.

Each receiver accepts a 5MHZ input from a cesium beam frequency standard for use in computing GPS solutions while tracking two satellites. In addition each receiver accepts synchronizing inputs of speed and heading as a source of back up aiding.

The satellite computer performs validity checks on all TRANSIT and GPS data to ensure that navigation data is not contaminated with unreasonable data. The data is then passed to the Navigation computer and the Navigation Operation Control (NOC). "Valid" data is used in determining best present position solution and "invalid" data is stored for possible post time reconstruction.

Each SRNS (MX-1107-GPS) receiver can be operated in a standalone configuration if necessary. In such a configuration, a special switching arrangement is used to printout position fixes at a selected rate to maintain navigation integrity.

System Software

Integration of the SRNS into the survey system required the development of software programs for the two computer systems presently being used on the ships. Three of these ships have a AN/UYK-20 computer based system whereas the fourth has a HP-1000E based system. The major software development efforts expended are described below:

Satellite Navigation Software

The Satellite Navigation Program is designed to perform the following functions: provide interface communications to the SRNS receivers and various peripheral equipment; process the GPS/TRANSIT data received and distribute this data to the Navigation and NOC computers. The following describes each function performed:

Interface Communications

The Satellite Computer, as shown in figure 2, interfaces to two SRNS receivers, two MINISINS, a Velocity Processor System (VPS), a GMT clock, the Navigation Computer and an operator console. The NOC utilizes the same data link as the operator console.

The Satellite Program performs operations based on three time intervals, all synchronized to the GMT clock's one second interrupt. These time intervals are required to perform one second processing, ten second processing and sixty second processing.

The one second processing performs the task of communicating to all peripherals except the Navigation computer and operator console. Each second all velocity sources are contaminated with unreasonable data. The data is then passed to the Navigation computer for use in determining TRANSIT position fixes and dead reckoning (DR). Additional interface options include: output of unprocessed GPS data, input of fine grid geoidal height data and computer controlled satellite selection.

The ten second process performs the function of determining the availability of GPS data, requesting GPS navigation data from the SRNS receivers and outputting GPS and TRANSIT data to the Navigation computer for use in the ship's Best Present Position solution (BPP).

The sixty second processing provides printouts of the GPS, TRANSIT and DR data received. This same data is provided to the NOC for use in display and system performance monitoring.

GPS Data Processing

The GPS data is requested every ten seconds when available from the receivers. This data is passed to the Navigation computer to be used in computing the ship's BPP. Prior to transferring data to the Navigation computer, the Satellite program performs a series of tests to determine the validity of the data. The validity tests were developed based on testing performed in the Simulation Integration Laboratory (SIL) at NAVAIRDEVCEN and aboard the survey vessels. These tests uncovered data anamolies during periods of high Horizontal Dilution Of Precision (HDOP), initial GPS data acquisition and GPS Joint Program Office (JPO) testing of the satellite constellation.

Initial Validity Test - This test is invoked during the initial acquisition of GPS satellites and when recovering from periods of high HDOP (HDOP>25) exceeding 5 minutes. The test automatically invalids the initial two minutes of GPS data and requires that HDOP to be less than 7 while navigating with...
two satellites and less than 16 when navigating with three or four satellites.

Normal Validity Test - Once the above test is satisfied, the normal DR test is invoked to detect problems caused by noise in the GPS data. In this test the HDOP limits are the same as the initial test and a comparison is made of GPS velocities to other system velocities. A DR test is performed using a radial position difference between the current and previous GPS position dead reckoned to the same point in time. The radial position difference must be less than 0.015 \times \text{DELTIM}/10, where \text{DELTIM} is the difference in seconds of time between the fixes.

High HDOP Validity Test - Dockside and at sea tests lead to the conclusion that satellite positions obtained with three and four satellites and HDOPs of between 16 and 25 still could provide the survey system with usable data. To ensure the acceptability of this data the velocity and DR comparisons described above were made more stringent.

Depending on the outcome of the normal and High HDOP validity tests, the GPS data is tagged valid or invalid, formatted and then transferred to the Navigation computer.

In addition to the automatic data validity tests of the Satellite program, the operator has the option to invalidate all GPS fixes. This feature is particularly useful during periods in which the GPS Satellite Segment is undergoing testing.

TRANSIT Data Processing

The Satellite Navigation program processes real time TRANSIT fixes and has the capability to perform near real time reprocessing of the TRANSIT fixes collected. The real time processing is performed to ensure the quality of the TRANSIT data by testing for the following criteria:

* Elevation Angle (between 10 and 70 degrees)
* Iteration count (< 7)
* Doppler ( > 10)
* Refraction Corrected fix
* Doppler count symmetrical about Center of Pass
* One Sigma (< 40 meters)
* Radial Position difference compared to SRNS DR position (20 miles)

If the fix passes these tests it is tagged as an updated fix allowing the Navigation computer to use it in predicting SINS corrections, then adds these corrections to the SRNS receiver where the fix is reprocessed. SIL testing has indicated the method used by the program to reconstruct the ship's position provides an improvement in accuracy over the method used within the SRNS receiver.

In addition, various routines were developed to permit the operator to perform functions thru parametric control rather than at the front panel of both receivers. To assist the operator in determining GPS coverage periods and TRANSIT availability required for mission planning, the program automatically prints out 24 hour alerts for GPS and TRANSIT.

Data Distribution

Up until now the discussion has focused on the processing of GPS and TRANSIT navigation data performed by the Satellite program. The distribution and usage of the data to monitor SRNS performance and accurately determine ship's position is the prime purpose of the integration.

The program distributes GPS and TRANSIT data to the NOC computer to provide the operator displays for data monitoring and to the Navigation computer for incorporation into the BPP computations.

Navigation Operation Control - The NOC provides the operator with real time displays to monitor the data and alarms received from both receivers and graphically displays all positional navigation aids (GPS, TRANSIT, SINS and LORAN C). This monitoring tool quickly alerts the operator to problems occurring in the SRNS receivers and thru out the survey system.

Navigation Program - The Navigation program's function is to determine the BPP of the ship every ten seconds. The manner in which the program uses the GPS and TRANSIT data to determine BPP differs due to the inherent difference in the data obtained from each. During periods when only TRANSIT positions are available, the Navigation program uses TRANSIT fixes for predicting SINS errors using a Maximum Likelihood Reset (MLR) equation. The MLR equation uses the SINS corrections calculated each updated TRANSIT fix to develop curve fit constants describing the 24 hour oscillation errors in SINS latitude and longitude, and the ramp component that may exist in the longitude error. The Navigation program in real time predicts SINS corrections, then adds these corrections to the data inputted from the SINS system to form BPP.

The use of GPS data differs due to it's continuous availability. When valid GPS data is available, it is filtered to resolve instantaneous noise and then is used as BPP. The SIL testing showed that there are periods when GPS positions contained high frequency errors. To reduce the effect of high frequency errors on the BPP solution, the differences between GPS and SINS position are applied to a low pass digital filter every ten seconds. To provide a smooth transition from the use of GPS data for BPP and MLR prediction of BPP, GPS measurements of SINS corrections are also used to define SINS errors.

SYSTEM PERFORMANCE/IMPACT

The SRNS equipment and associated system hardware and software changes were installed on the four ships in summer/fall 1986. Initial tests and evaluations lead to several changes in SRNS firmware and survey system software to improve the overall performance of the system and to extend the availability of useful GPS data.

HDOP Limits

As described above, dockside tests revealed that the HDOP limits initially selected for the Satellite program were prohibiting the system from using otherwise acceptable data for real time navigation. Since the goal of this integration was to provide extended satellite navigation data, new limits and evaluation criteria were established based on the data obtained in the field. As a result the integrated system provides more usable real time data than that obtainable using the original HDOP criterion. Additionally these tests revealed that the HDOP criteria used in the SRNS receivers themselves needed to be changed to prevent the receivers from providing erroneous navigation data during periods of extremely high HDOP.
Navigation with Two Satellites

The capability to obtain position data with only two GPS satellites in view has typically provided an additional 2 to 4 hours of data per day. The quality of data obtained using only two satellites is subject to the various conditions existing prior to the two satellite coverage, including the quality of the external frequency being used and satellite coverage available before transitioning to two satellites. The integrated system is essential in determining the utility of this data.

Summary

The integration of the SRNS into the survey system has had a dramatic impact on position accuracy in areas without LORAN C coverage. It also has provided the ships with the capability to run the ship's Track Keeping System (TKS) in these areas, improving the quality of the magnetics, gravity and bathymetric data collected. In areas of high vertical deflections and during changes in ocean current, it provides the system with the capability to detect SINS schulers and thus improve navigation. The integrated system provides an accurate measurement of SINS error every half hour allowing the Navigation System to improve the prediction of SINS performance and thus improves the position accuracy during periods when GPS satellites are not available.

Reference