GPS Equipped Sonobuoy

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Abstract

Sonobuoys equipped with a Global Positioning System (GPS) prove extremely useful when calibrating underwater sonar systems. Hermes Electronics Inc., in collaboration with Defence Research Establishment Atlantic (DREA) has developed such a buoy. The sonobuoy is a modified version of Hermes AN/SSQ53D(2) DIFAR sonobuoy. Modifications include de-sensitizing the acoustic receiver, installing a commercial GPS engine, and providing an electronic interface between the buoy and the GPS unit. Modulation interference with DIFAR pilot tones and power considerations required that the directional channels be disabled. Buoys were tested with a passive patch antenna and an active (powered) antenna. The quality of the binary data transmitted from the buoy was assessed using GPS Real Time Kinematic (RTK) software developed by Waypoint Consulting. In this paper the sonobuoy modifications are outlined and results obtained with the buoy during two sea trials are presented.

Introduction

Very often, the need arises to calibrate underwater acoustic sources in open sea environment. The use of a sonobuoy as a free floating, acoustic receiver linked to a ship through a very high frequency (VHF) transmitter on the buoy and a VHF receiver on board the vessel is a convenient solution. With a remote acoustic receiver, a ship is free to tow an acoustic source in close proximity to the sonobuoy receiver and information on the source characteristics can be gained by analyzing the sonobuoy's acoustic data. One of the problems with a free-floating receiver is in knowing its exact location. A sonobuoy does not present a large radar target, and tracking one on radar is difficult. If the buoy is equipped to send information on its position (latitude and longitude) along with its acoustic data, then the problem is reduced. Fig. 1 shows the concept of a GPS equipped sonobuoy system. Defence Research Establishment Atlantic (DREA) conceived and constructed an early version sonobuoy incorporating GPS positional information in the data telemetry in 1997, [Davis and Scott (1)]. In December 1998, DREA issued a contract to Hermes Electronics Inc. to design and produce a special-purpose sonobuoy that features an acoustic hydrophone and a low-gain preamplifier. This allowed the sonobuoy to operate in environments of high sound pressure levels typical of close range low frequency active (LFA) sound sources. The response of the calibrated acoustic sensor is omni-directional, which is suitable for characterizing LFA towed acoustic sources. The sonobuoy is equipped with a Global Positioning System (GPS) receiver and the data from the

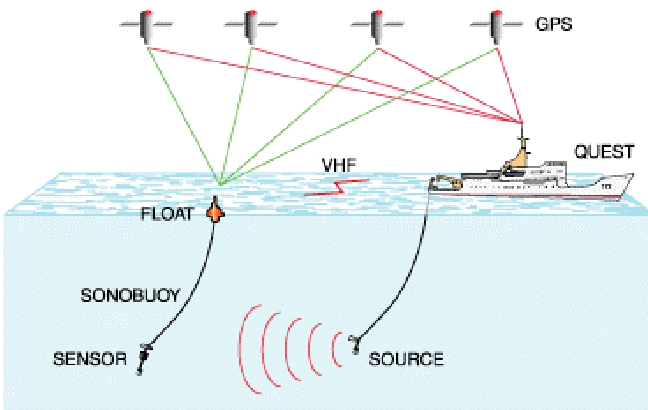

Figure 1. GPS Sonobuoy Concept

GPS receiver is embedded in the radio frequency (RF) transmission from the buoy. This paper describes the sonobuoy system, including the buoy configuration, the shipboard receiver system and the software to retrieve the GPS positional data.

System Overview

Fig. 2 shows the GPS equipped sonobuoy system block diagram. The diagram illustrates the functional blocks of the system (both hardware and software) and their connection to other system components. The GPS equipped sonobuoy system is divided into two functional units: the sonobuoy itself (Fig. 2a) and the shipboard system (Fig. 2b). The buoy is considered first.

An acoustic hydrophone and electronic preamp are housed in a pressure vessel. This assembly is referred to as the lower electronics unit (LEU). The output acoustic signal is connected to the upper electronics unit (UEU) through a wire and compliant suspension. The UEU also houses the GPS engine and the GPS antenna. A microprocessor in the UEU programs the GPS receiver to send specific binary data words at 9600 baud to the transmitter. This binary data modulates a 57.6 kHz sub-carrier. The sub-carrier and the acoustic data from the hydrophone assembly combine to frequency modulate the RF carrier of the sonobuoy transmitter in the UEU. The surface float is a small air-filled vinyl bag. The VHF transmitter antenna runs from the top of the 300 mm inflatable float to a metal plate at the

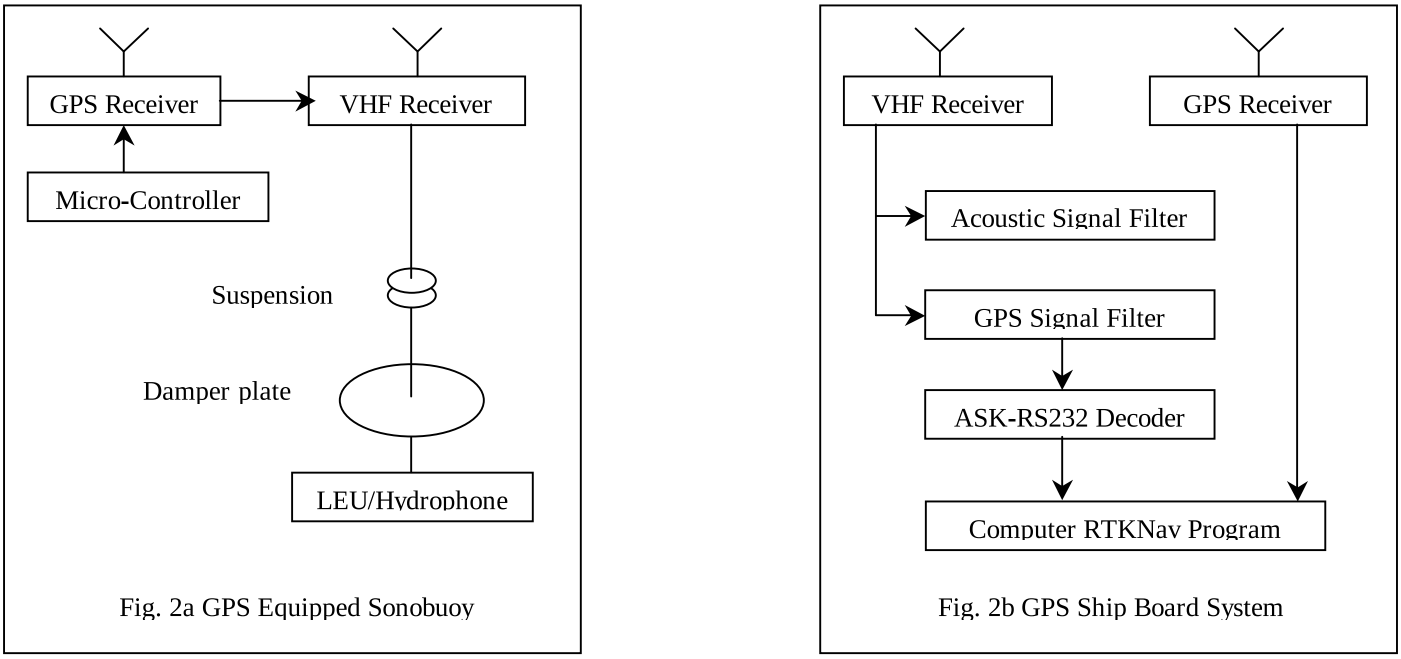

Figure 2. GPS Equipped Sonobuoy System Block Diagram

top of the UEU. An end-of-life scuttling circuit is disabled allowing for post-mission recovery of the sonobuoy.

On board the ship, a VHF receiver tuned to the correct channel receives the sonobuoy RF signal. The receiver output is connected to two filters. A low pass filter set at 3000 Hz filters the acoustic data. A separate band pass filter (pass band 50 kHz to 63 kHz) retrieves the sonobuoy GPS data. Thus the 57.6 kHz sub-carrier with the GPS data is isolated. A separate custom decoder circuit restores the RS-232 binary data words from the sub-carrier. This data is fed to the communications port (COM port) of a personal computer (PC). A second GPS receiver is located on the upper deck of the ship and serves as a base station. The corresponding RS-232 data stream from the base station is fed to a second COM port on the PC. This allows the software installed and running on the PC to process real time relative kinematic (RTK) positioning information of the relative location of the remote sonobuoy with respect to the shipboard base station. Several information windows are available in the software graphical user interface (GUI). One such window is the plotting routine that traces the navigational track of the base station and the remote sonobuoy with a pixel "crumb" trail. Since GPS updates (epochs) occur every second, a clear picture of the past movements of all remotes and the base can be gained at a glance. The shipboard system hardware is capable of receiving and tracking up to four buoys and one base station simultaneously. The software running on the PC can be configured for up to 20 buoys simultaneously.

Detailed Description of the GPS Equipped Sonobuoy

Hydrophone and Lower Electronics Unit

Hermes Electronics Inc. modified a regular production sonobuoy (Model AN/SSQ53D(2) DIFAR) to use as a test bed for the GPS equipped sonobuoy. The hydrophone and preamp module comprise the lower electronics unit (LEU). The omni hydrophone is unchanged from the production AN/SSQ53D(2) DIFAR and the directional hydrophones, although present, are not used. The sensitivity of the omni hydrophone is -210 dB re 1 Volt/µPa at 1 kHz. The standard LEU circuit board is replaced with a board containing only a preamplifier and line driver for the omni hydrophone. The standard pre-whitening filter circuitry and the electronics to process the directional (DIFAR) channels are also removed and the original preamplifier is modified to provide lower gain. This ensured that the high signal levels of LFA acoustic sources do not overload the sonobuoy system. When a 1000 Hz acoustic signal with a sound pressure level of 194.9 dB re 1 µPa is present at face of the sensor, the shipboard sonobuoy receiver produces an output signal of 1.0 volts RMS (0.0 dBV). Two filter circuits in the LEU shape the frequency response of the preamplifier. A high pass filter at 104 Hz and a low pass filter at 3000 Hz form a pass band response that is nominally flat in the region from 100 Hz to 3000 Hz. Acoustic signals below100 Hz and above 3000 Hz are

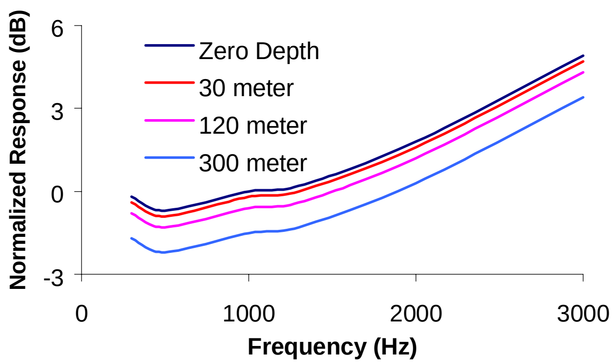

Figure 3. GPS Sonobuoy Normalized Frequency Response Versus Depth

out of band for the LFA application of the GPS equipped sonobuoy. The response of the hydrophone and preamp is dependent on depth. Fig. 3 shows a typical normalized response versus frequency for three different depths. A calibration curve for each GPS equipped sonobuoy ensures that the response of each buoy is known.

Cable Suspension and Deployment

A standard "A" size canister houses the GPS sonobuoy. Fig. 2a shows the layout of the various components: the float, the UEU, the suspension pack, the LEU, and the acoustic sensors. Prior to deployment, the user must program the buoy for the intended mission. The program options such as the RF channel number, the deployment time and the depth of the acoustic receive system are selected through a menu-driven push button choice on the side of the canister. The deployment times are half hour, one hour, two, four and eight hours and the available depths are shallow (30 m), medium (120 m) or deep (300 m). Referring again to Fig. 2a, the suspension cable consists of a spring/mass system to reduce the effects of the surface wave motion on the receive sensors. A large spring/mass system is effective in reducing the wave motion on the receive sensor. However, the surface area of the mass increases the horizontal displacement between the sub-surface system and the surface float, especially in large shear currents or high surface winds. Thus a small 0.3 m circular damper plate is used to increase the effective mass and at the same time, minimize the horizontal displacement due to drag. Hermes Electronics modeled the performance of the 0.3 m circular damper plate. At a depth of 300 m, the model predicted a horizontal displacement of 10 m in a shear current of 2 knots.

GPS Receiver in the Sonobuoy

The GPS sonobuoy uses a Rockwell (Conexant) Jupiter LP (Model TU30-D160-011) GPS receiver. It is a single frequency receiver in the L1 band (1575.42 MHz). The 12 parallel channel capability allows simultaneous tracking of 12 GPS satellites. The low power (LP) version features lower power consumption than the conventional model, requiring only 145 mW for continuous operation at 3.3 VDC. Low power consumption is an important consideration as a salt-water battery powers the buoy. One can configure the Jupiter LP receiver to accept either a passive or an active antenna. Hermes Electronics produced 20 buoys with passive antennas (Micropulse model 1621AW/C) and 10 buoys with active antennas (SiGem model SGM3902PMX). The active antenna provides a gain of 13 dB providing better satellite reception. This active antenna comes at the price of increased power consumption. The SiGem antenna draws 7 mA when operating at 3.3 volts. The active antenna version of the sonobuoy was first used during the DREA sea trial in March 2001. Although only three buoys featuring the active antenna were successfully deployed, they demonstrated improved satellite reception over the passive models. Where the passive-antenna buoy might receive four to five GPS satellites per epoch, the active-antenna buoy would track five to six GPS satellites. It is important to note that at least four satellites are required to satisfy the relative positioning algorithm. The stability of the position solution increases with the number of satellites received. Sea state plays a large part in the ability of the GPS engine to remain locked on the satellite signals. The random movement of the float as it is buffeted by the surface waves deteriorates the satellite signal lock considerably. This effect is difficult to quantify and will become the focus of future trials.

GPS Interface Board

The Jupiter LP GPS receiver resides as a "daughter board" on the GPS Interface Board, a custom printed circuit Hermes Electronics designed and produced. The GPS interface board sits in the upper electronics unit of the AN/SSQ53D(2) DIFAR. The UEU has a spare card slot available and only minor alterations in the other boards are necessary to accommodate the presence of the GPS Interface board. The circuitry includes a crystal oscillator operating at 3.6864 MHz that clocks a micro-controller, the Amtel AT90S2313-4. This device is programmed at the time of manufacture and it communicates with the Jupiter receiver when power is applied to the buoy. It tells the Rockwell Jupiter receiver to turn off some default messages, what data to send, and at what baud rate to send the data. Table 1 shows the execution steps of the micro-controller program.

DREA consulted Waypoint Consulting of Calgary, Canada, authors of the navigational software package, RTKNav, to determine which GPS data words are required from the sonobuoy.

Table 1. GPS Interface Micro-Controller Program

1	Start
2	Enable UART transmitter
3	Wait 1 second
4	Bring Jupiter out of reset
5	Wait 1 second
6	Send message 1330 (Serial Port Parameters
7	Wait 0.5 seconds
8	Send message FFFF (Disconnect All Messages)
9	Wait 1.1 second
10	Send message FFFF (Disconnect All Messages)
11	Wait 1.1 second
12	Send message1000 (Geodetic Position Status)
13	Wait 0.5 seconds
14	Send message1102 (Measurement Time Mark)
15	Wait 0.5 seconds
16	Send message1221 (Navigation Configuration)
17	End

Table 2. GPS Binary Data Transmitted

Message	Message Name	words	bits
1000	Geodetic Position Status	55	1100
1002	Channel Summary	51	1020
1003	Visible Satellites	51	1020
1102	Measurement Time Mark	253	5060
1108	UTC Time Measurement Pulse	20	800

These critical words for the Rockwell Jupiter GPS engine are: Message 1000 (Geodetic Position Status) and Message 1102 (Measurement Time Mark). Some default messages (1002, 1003 and 1108) are still sent even after the Disconnect-All-

Messages command is delivered to the Jupiter receiver. Table 2 shows all the GPS binary messages transmitted from the GPS receiver after the programming routine is executed as well as the number of words/bits in each of the messages (two bytes per word, 10 bits per byte). Thus the GPS buoy transmits a total of 8600 bits of binary data per second at 9600 baud. Data is present for 0.896 seconds and absent for 0.104 seconds before the next data transmission begins. A 16-stage counter divides the 3.6864 MHz crystal oscillator used to clock the micro-controller. This produces a 57.6 kHz square wave. The binary data from the GPS receiver toggles this square wave on and off in accordance with the polarity of the binary data and the result is an amplitude shift-keyed (ASK) modulation of the 57.6 kHz signal. This encoded sub-carrier modulates the sonobuoy RF carrier. A variable resistor on the GPS interface board adjusts the sub-carrier signal amplitude to ensure correct deviation of the RF carrier in the sonobuoy transmitter circuit.

Sonobuoy Transmitter

The frequency modulation (FM) transmitter circuitry of the GPS equipped sonobuoy is based on the phase locked loop (PLL), 99-channel VHF transmitter developed at Hermes Electronics for the USN AN/SSQ53E sonobuoy. This transmitter's full power output is typically 1 watt. The GPS sonobuoy incorporates design changes to the transmitter's modulation crossover frequency circuitry. The full-scale deviation of the RF carrier is 75 kHz. The GPS data causes the RF carrier to deviate 7.5 kHz while the acoustic signal from the hydrophone deviates the RF carrier by a maximum of 67.5 kHz. With the GPS signal and the acoustic signal at the maximum, the full-scale output of the standard sonobuoy receiver, Model AN/ARR-75 is 2.0 volts RMS. The possibility of interference between the fundamental VHF frequency of the transmitter and the GPS receiver was investigated. Tests on the first 31 channels of the sonobuoy's RF band (162 MHz to 174 MHz) revealed no interference problems in the reception of the GPS signals. The ASK modulation of the GPS data does, however, result in side band noise evident in the base band spectrum of the sonobuoy receiver output. Discrete component filters in the transmitter prevent this noise from contaminating the acoustic frequency band of interest. Spectrum measurements indicate that the side band signal levels at frequencies below 3000 Hz are down by 65 dB below the 57.6 kHz sub-carrier fundamental. Thus, no adverse effects of the sub-carrier are evident in the acoustic signals.

Detailed Description of the Shipboard System

Shipboard Sonobuoy Receiver

As stated, the sonobuoy receiver is a Model AN/ARR-75. Capable of receiving four buoys at one time, this FM receiver can be tuned to the first 31 RF channels of the 99-channel sonobuoy band. Channel numbers are interleaved: Channel 1 is at 162.250 MHz, Channel 17 is at 162.625 MHz, Channel 2 is at 163.000 MHz up to Channel 31 at 173.125 MHz and channel 16 at 173.500 MHz. A band of 375 kHz separates each channel. During the first DREA trial (February 2000) the VHF antenna system was mounted on the uppermost deck of CFAV Quest and did not use an antenna preamplifier. Maximum range of reception was about three to four kilometers. In the second DREA trial (March 2001) an RF amplifier with 16 dB of gain was inserted in the antenna line about 20 meters from the antenna. The antenna itself was raised about 10 meters higher than the previous trial to the ship's main mast. These changes extended the reception range of the sonobuoy to over eight kilometers. Sea state also plays a large part in limiting the range of the GPS reception from the buoy. High waves that wash over the sonobuoy surface float, or shield the transmission from the buoy to the ship cause serious dropouts in the RF signal and as a result in both the GPS and acoustic data. In the two trials conducted, reasonable contact with the sonobuoy was maintained up to sea state 3. Noticeable degradation in the quality of GPS data transmissions occurred in sea state 4 and above. Seas higher than sea state 5 were not experienced in either trial.

Acoustic and GPS Data Filters and GPS Data Restoration

The shipboard receiver output feeds two filter configurations. A low pass filter (eight pole Butterworth) set at 3000 Hz recovers the acoustic signal that is then recorded and analyzed to determine the power spectrum of the hydrophone signal. A band pass filter (eight pole Butterworth) set to 50 kHz and 63 kHz recovers the GPS data. This extracts the ASK modulated sub-carrier (57.6 kHz) that contains the sonobuoy GPS data. A custom electronics decoder chassis demodulates the sub-carrier using a Mitel integrated circuit MT8840 (data-over-voice modem) configured as a demodulator. The GPS binary data appears at the chassis output in an RS-232 format (9600 baud, eight data bits, no parity, one stop bit). The processing software running on the personal computer requires this data at a COM port. Once received the software assigns a remote designator to the data (R1 for example). Each sonobuoy deployed must have a dedicated sonobuoy receiver channel, a separate acoustic and GPS data filter, and a GPS data demodulator circuit. DREA's current shipboard GPS system will accommodate up to four sonobuoys simultaneously transmitting data.

Base GPS Receiver on the Ship

The base GPS station is mounted on board the ship. The base station GPS antenna is the point from which the measurements of range and bearing to the sonobuoy are referenced. DREA uses a Rockwell Jupiter GPS engine housed in a small chassis. This commercially available "development kit" includes an active GPS antenna, an RS-232 interface electronics, and a power supply. Switch settings on the chassis configure the output data format. Data is set for Rockwell binary words (vice NMEA-0183 ASCII text strings) at 9600 baud, eight stop bits, no parity, one stop bit. The RS-232 output data is sent to an unused COM port on the PC. The processing software assigns the "Base" designator to the data.

RTKNav Software Program

Waypoint Consulting (Calgary, Canada) produces computer software that performs real time GPS processing. Their product, RTKNav includes real time processing for up to 20 remote receivers, using features like kinematic ambiguity resolution, moving baseline, and heading determination.

RTKNav runs on Windows 9x/NT and is able to create windows that display the updated satellite data, solution data (range and bearing of the remotes), processing and receiver status at every epoch. A plot of the base station

and its remotes can also be viewed and modified to focus on a specific receiver. DREA has tracked up to three remotes on sea trials. Discussion on the nature of the processing is outside the scope of this document but Waypoint Consulting's web site provides more information [Waypoint Consulting (2)].

Fig. 4 and Fig. 5 show samples of actual window displays of RTKNav during the DREA trials. Fig. 4 is taken from the trial on 14 February 2000. Several data windows are displayed. The "Plot View – Master" window (pixel map) depicts the track of one remote sonobuoy receiver ("R2" in green) and the track of the moving base (research vessel CFAV Quest designated "B" in blue). It traces the ships "bow-tie" maneuver over the course of almost three hours and shows the sonobuoy's drift during that same time. The "Solution Data View – Remote 2" window indicates positional information of the sonobuoy at the time of the last positional fix. The window displays the latitude (Lat) and longitude (Lon) as well as the relative position (Local Level) of the remote from the base. This information is given as an easterly offset (E) in meters and a northerly offset (N) in meters. Negative values represent westerly and southerly offsets respectively. The "Vector View – Master" window shows calculated range and bearing (true) of the remotes R1 and R2.

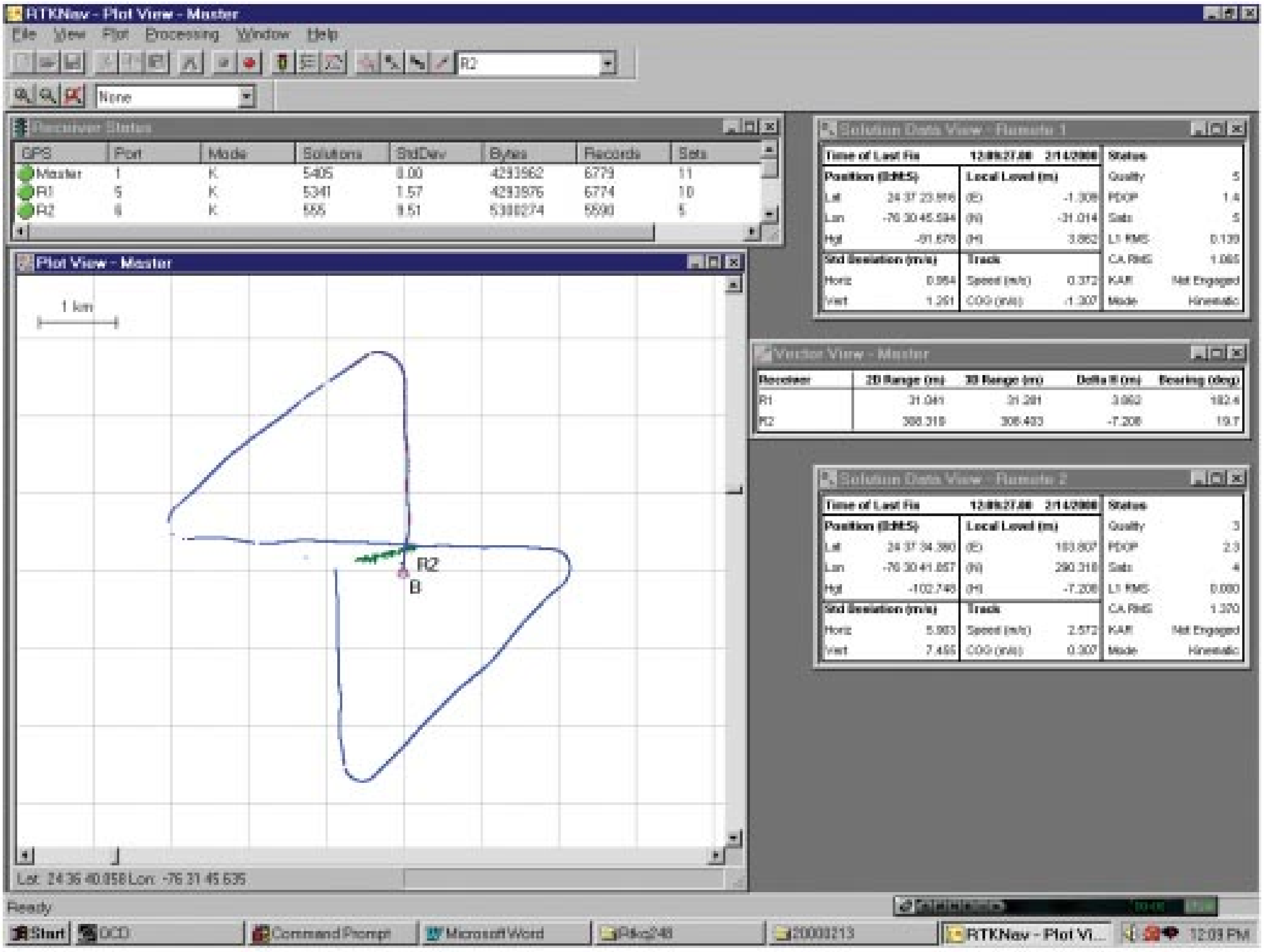

Figure 4. Sample RTKNav Window Display of 14 February 2000

Fig. 5 shows the "Plot View – Master" window display from RTKNav during the DREA trial on 24 March 2001. The pixel map displays the vessel (CFAV Quest designated "Base" in blue) proceeding on a "closest-point-of-approach" to the drifting sonobuoy (designated "R1" in red). The past track of the sonobuoy's drift is very clear and the zoom features of RTKNav allow close inspection on the precision of the relative position data. The ring markers are spaced at 30m. Very few pixels lie outside a 10 m track. Notice that the red pixels are not evenly spaced like the blue pixels. This indicates that the fixes from the sonobuoy are not received each second. Sea state, antenna shielding and loss of satellite lock preclude data reception at every epoch. However, there are plenty of data points to determine the course of the sonobuoy.

The RTKNav software includes a wide range of features such as TCP/IP network broadcast of the relative position information, status and signal strength for the satellites in view, processing messages regarding data quality, and many more. A complete description of RTKNav is available at the Waypoint website (2). Post processing of the recorded data files (in various formats) allows for a more rigorous treatment of the track reconstruction. Additional Waypoint software programs (for example GrafNav) allow for a thorough assessment on the quality and accuracy of the positional data.

Buoy Performance on Trials and Conclusions

DREA deployed 17 GPS equipped sonobuoys with passive GPS antennae during the trail in Feb 2000. Four failed to operate properly. Problems included faulty RF transmission, and incorrect GPS data composition. Accurate location fixes were maintained for ranges greater than four kilometers. Five buoys with active GPS antennae were deployed during the trial in March 2001. Two buoys failed to operate properly. Buoys with active antennae generally tracked more satellites and reported more location fixes than buoys with passive antennae. Tracking the position of the surface float to an accuracy of 10 meters is routine. In conditions of low sea state and robust GPS satellite reception, accuracy to within 3 meters is possible. Improvements in the shipboard VHF receiver antenna system extended the range out to eight kilometers. The inherent difference in horizontal displacement between the sonobuoy surface float and the underwater sensor ultimately limits the accuracy of determining the exact location of the acoustic sensor. Hermes Electronics Inc. has provided DREA with a useful tool for assessing the performance of high power underwater sound sources. Plans to use the present system to bring the GPS capability to a full sensitivity, directional sonobuoy are underway. This will require new modulation techniques for the GPS binary data. Smaller, and lower power GPS receivers are also under consideration to help offset the increase in power required when the functionality of the DIFAR circuitry is restored and the gain is increased to that of a standard sonobuoy.

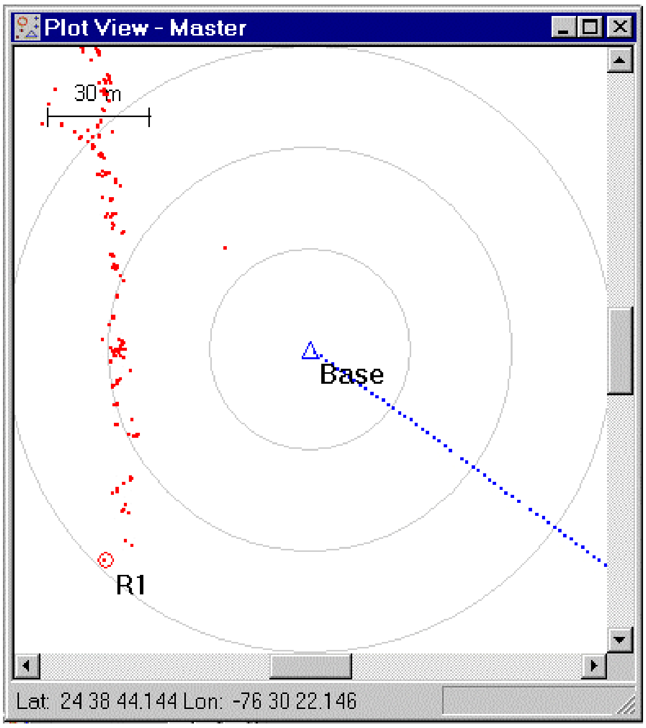

Figure 5. Sample RTKNav Window Display of 24 March 2000

References

(1) Davis, B. and Scott, Capt.R., "Development of a Prototype GPS-Equipped Sonobuoy," (informal report), May, 1994

(2) Waypoint Consulting Inc., "RTKNav Real Time Multi-Remote GPS Processing Software Version 2.0," http://www.waypnt.com , April 2000