SEA*DeViL* A Totally Integrated Inertial Navigation System (INS) Solution

By: William Alameda, Jr.

Underwater Intervention Symposium, 2002

New Orleans, LA
February 27 – March 2, 2002

ABSTRACT

Kearfott Guidance & Navigation Corporation (Kearfott) has successfully developed and integrated a product line of Inertial Navigation Systems/ Global Positioning Systems (INS's/GPS's). These systems are the result of the incorporation of GPS with an INS configured with Kearfott's patented Monolithic Ring Laser Gyro (MRLG) and single-axis navigation accelerometers. The design balances mission requirements, reliability, and cost. Kearfott has utilized its proven Seaborne Navigation (SEANAV) system in conjunction with RD Instruments state of-the-art line of Doppler Velocity Logs and an embedded GPS as the basis for the development of the integrated INS named SEA*DeViL*. The modular design provides the user a greater flexibility in configuring the SEA*DeViL* for particular mission scenarios. The INS components in the SEA*DeViL* system are virtually identical to those utilized in Kearfott's MILNAV, AIRNAV and SEANAV INS's with the differences identifiable to application-specific software. The DVLs used are standard Commercial-Off-The-Shelf (COTS) provided by RD Instruments, a leader in developing and manufacturing of DVLs.

The hardware commonalities in SEA*DeViL*, employ a Commercial-Off-The-Shelf (COTS) approach, resulting in a broad manufacturing base incorporating Six-Sigma producibility methods. SEA*DeViL*'s heritage with other Kearfott environmentally robust products, is capable of performing during exposure to as variety of adverse mission scenarios.

Sea*DeViL* was introduced to minimize alignment errors and correctly interface the INS with the DVL and the GPS receivers. By reducing or eliminating these errors clients' costs are reduced and the integration time of a new or updated system is greatly reduced, thereby making such an integrated system attractive and available to a wider market.

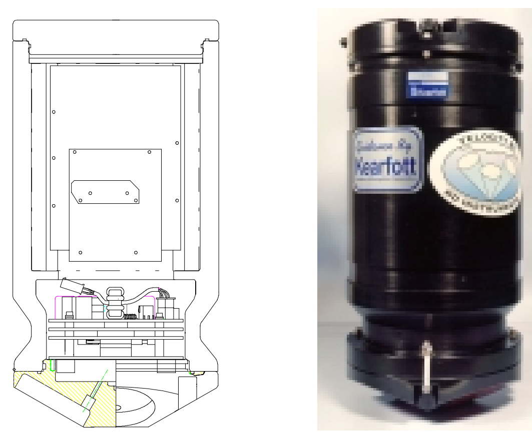
SEA*DeViL* is Kearfott's and RD Instruments response to the ever increasing demand for the use of advance technologies in the marine environment to resolve navigation and positioning problems associated with increasing deeper and more complex mission. This paper provides a brief description of the SEA*DeViL* system architecture and performance expectations.

INTRODUCTION

SEA*DeViL* Hardware Architecture

The SEA*DeViL* (Figure 1.) is a compact system representing a major breakthrough in marine sensors providing highly reliable heading, attitude, navigation and vehicle dynamic data to appropriate user subsystems. The SEA*DeViL* is a modular design allowing the use of two (2) MRLGs and three (3) DVL choices. As shown, the SEA*DeViL* system is a compact modular design with overall pressure vessel dimensions of 18 in height x 9 in OD. The chassis is designed to provide a watertight pressure to either 1000, 3000 or 6000 meters. If required a custom pressure housing can be accommodated for unique applications.

Figure 1. SEA*DeViL* Hardware Architecture



The Inertial Sensor Assembly (ISA) used in SEA*DeViL* is supported by elastomeric isolators to mounting pads / bracket assembly, which are mounted to the pressure vessel and located through alignment pins. The ISA contains a three-axis MRLG, a triad of orthogonal single-axis pendulous accelerometers with pre-amps and an MRLG electronics card to service the fringe detection and provide dither drive.

Two electronics cards, identified as a Digital Circuit Card Assembly (CCA) and an Analog CCA, are mounted to a heat sink, which is mounted to the housing.

The Digital CCA provides:

- Digital Signal Processor (DSP) and memory/control logic
- I/O functions.

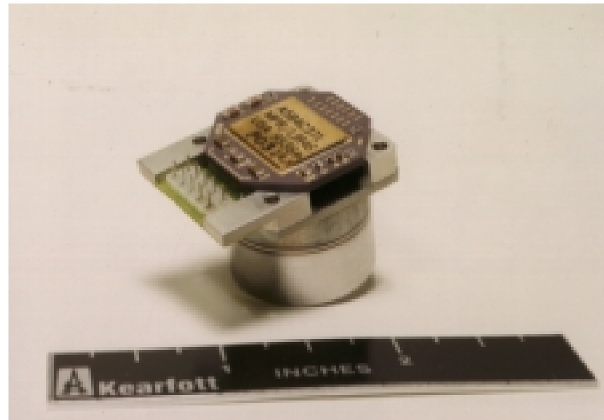
The Analog CCA provides the IMU electronics:

- Interface between the DSP and conditioned instrument sensor data
- Gyro and accelerometer electronics
- Multiplexed A/D
- High-Voltage Power Supply (HVPS).

The Low-Voltage Power Supply (LVPS) is mounted on a separate module, which also provides Electromagnetic Interference (EMI) filtering.

Figures 2 and 3 display the inertial components. The MOD VIIA (Figure 2) accelerometer is a single-axis, pendulous, force rebalanced and squeeze film-damped instrument. This strapdown application version has its heritage in the Kearfott MOD VII accelerometer, successfully utilized in aircraft INS applications and produced in quantities in excess of 40,000 over a three decade period. The SEA*DeViL* contains a triad of such instruments, in a mutually orthogonal configuration, mounted to the undithered ISA member.

The Kearfott three-axis MRLG is shown in Figure 3. This unique design is constructed in a single glass block featuring one-dither mechanism, which is symmetrically disposed to the three orthogonal gyro axes. Each axis laser path is square utilizing shared mirrors. The T24 and T16 instruments, shown in Figure 3, are designated according to path length, i.e., 24 cm and 16 cm respectively, thereby offering different levels of performance.



56340-2

Figure 2. MOD VIIA Accelerometer

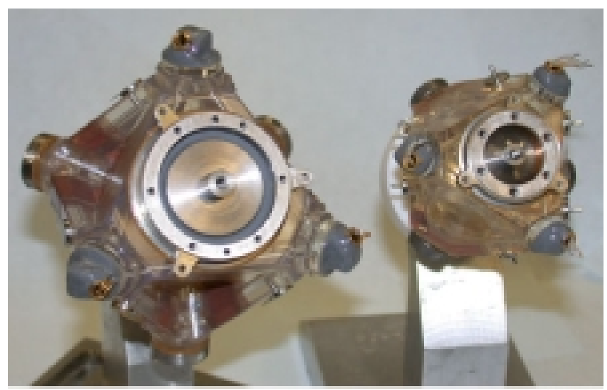


Figure 3. T24 and T16-B Monolithic Three-Axis Ring Laser Gyros.

<u>SEA*DeViL* System Block Diagram</u>

Figure 4 is a simplified diagram depicting the relationship of system hardware components with an attempt to emphasize the functional operability. Direct control of the SEA*DeViL* can be exercised via a CDU (generally user supplied) or by PC through connector J2 for lab testing or operational control. GPS, Doppler Velocity Log (DVL) and other aiding devices may be utilized independently, in combination, or not at all.

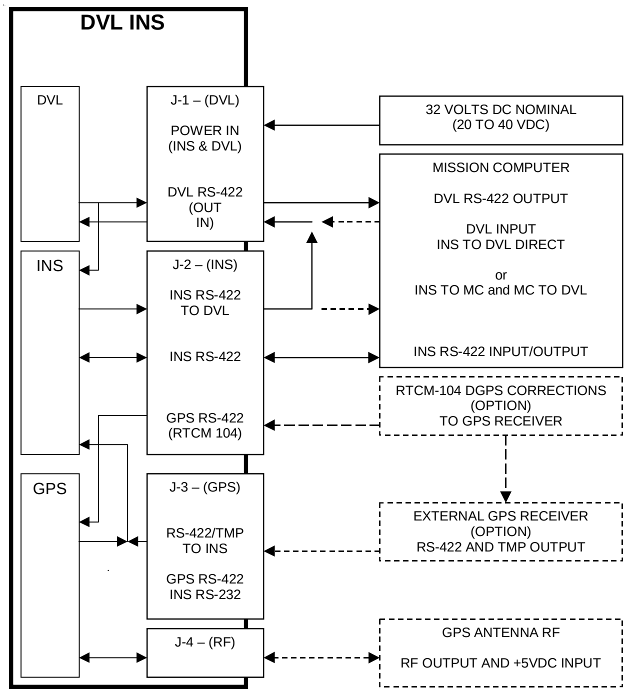


Figure 4. SEA*DeViL* System Block Diagram

The processes of alignment, calibration, and navigation are concurrently performed. Errors in state estimates of navigation parameters and calibration parameters, as influenced by observation and process noises, are predicted by covariance analysis. Figures 5. and 6. offer an example of these performance error estimates for the SEA*DeViL* INS.

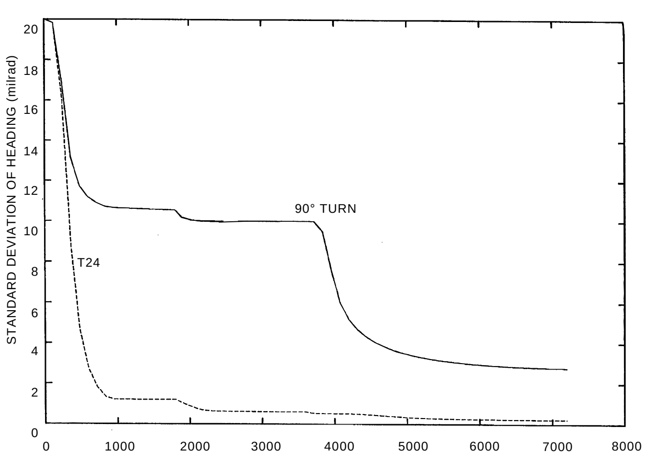


Figure 5. Heading Error - Covariance Analysis

Analyses performed, for both T16 and T24 gyros, are shown where the Angle Random Walk (ARW) of the T16 is 10X larger than for the T24.

The operational scenario includes a 15-minute moving-base GPS velocity aided alignment, followed by a free inertial dive to 2,500 ft, followed by DVL bottom tracking for the remainder of the time. Bottom trajectory is straight line except as interrupted by a 90° turn after one hour.

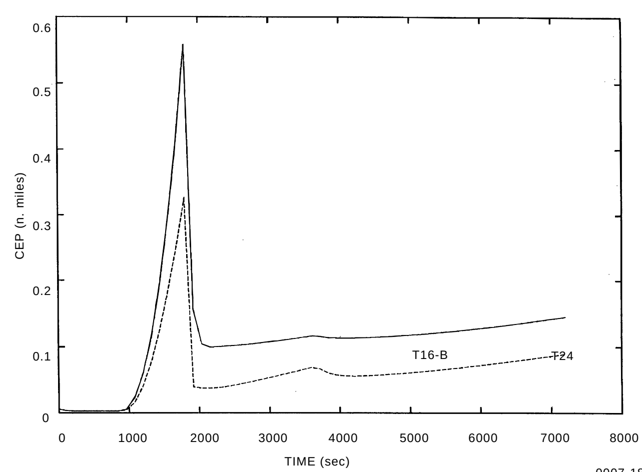


Figure 6. Position Error - Covariance Analysis

The quality of the moving base alignment is shown in Figure 5 by the rapid decrease in heading error during the 15-minute alignment period. Although the heading error rate is decreasing, the alignment is not complete. The difference between the T16 and T24 error plots results from the higher ARW and bias levels (>10:1 ratios) of T16 relative to T24. During the same period, CEP as shown in Figure 6, is negligible due to GPS position fixing.

During the dive to sea bottom, a 1,000 second interval, the systems are free inertial (no aiding) and the CEP shows a steep error rate. The resulting CEP build-up is largely recovered when the vehicle switches to DVL bottom tracking. This is a result of the strong correlation between velocity and position and the reestablishment of a velocity reference at the start of DVL tracking. Moving base alignment, which was interrupted at the start of dive, is resumed with the application of DVL bottom tracking. CEP error rate for the remainder of the mission is dominated by DVL scale factor and boresight errors.

The 90° turn, executed at one hour from start, permits improved heading alignment by orienting the previously biased gyro axis east, exactly as is accomplished in the two-step stationary base gyrocompass. The T16 results benefit significantly more than the T24 results, as a consequence of the bias and ARW differences between the two instruments.

DOPPLER VELOCITY LOG (DVL)

The RD Instruments DVL uses four beams in a Janus configuration to obtain velocity in three dimensions. The Janus configuration is particularly good for rejecting errors in horizontal velocity caused by tilting because the two opposing beams allow vertical velocity to cancel, when computing horizontal velocity and attitude uncertainty (pitch/roll) cause only second order single-beam velocity errors. Bottom tracking, utilized by SEA*DeViL*, requires use of long pulse transmissions to fully illuminate the bottom over the entire beam all at once. Bottom tracking has a typical single-ping accuracy of a few mm/s and depth resolution is approximately 0.1 meter. Maximum altitude (distance from the bottom) is a function of transmission frequency and transmitted power (See Figure 7.).

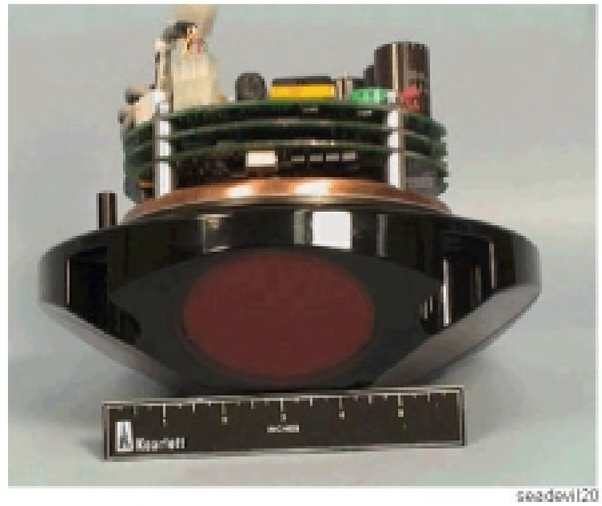


Figure 7. 300 kHz DVL

GPS/DGPS RECEIVER

Two GPS configurations possible with the SEA*DeViL*. One is an embedded GPS receiver circuit card. The other (optional) couples a customer provided standalone GPS/DGPS receiver, which is physically separated from the SEA*DeViL* and electrically connected by a dedicated cable. The optional standalone GPS receiver may be either a U.S. Department of Defense (DOD) C/A P/Y code GPS receiver (providing a Time Mark Block 03 message) or a maritime GPS (or DGPS) receiver (providing selected NMEA 183 data messages) and a 1 Hz time synchronization pulse (Time Mark or 1PPS). The SEA*DeViL* navigation software is unaffected by which GPS receiver is utilized. Provision is made for the customer to provide RTCM 104 DGPS corrections to the embedded GPS receiver.

SOFTWARE ARCHITECTURE

The software architecture is structured into three programs: the DVL computer Program, the IMU Computer Program (IMUCP), and the SEA*DeViL* Application Computer Program (ACP). The IMUCP, coded in “C”, performs the high-speed front-end inertial sensor data processing and inertial sensor control. The SEA*DeViL* ACP, coded in Ada, performs the inertial strapdown navigation computations utilizing the IMUCP output data. Kalman filter algorithms utilize data from the DVL computer program, the embedded (or external) GPS receiver plus inputs from the control computer for alignment and hybrid navigation, application specific functions, and system I/O.

INTERFACE/DATA DESCRIPTION

The SEA*DeViL* offers a full duplex asynchronous RS-422/RS-232 interface. Time tagging of data in GPS time is provided if one of the GPS options is exercised.

The serial interfaces support a set of messages providing inputs to and outputs from the SEA*DeViL*. These messages can be easily adapted to application output rate, baud rate and content requirements. The maximum output data computation rate is 50 Hz.

SYSTEM TESTING

Kearfott and RDI completed development of the SEA*DeViL* system in mid 2001 and commenced initial integration testing near RDI's facility in San Diego using a surface vessel, See Figure 8. Preliminary results revealed that the Kalman filter initial uncertainty of the misalignments (between the inertial sensor and DVL sensor) resulted from the accurate machining and rigidity of the system housing. To properly model the SEA*DeViL* dynamics, a reduction from 2 1/2 degrees to 1/2 degrees (10 mils) improved overall system performance as seen in Figure 9. test results. Further testing demonstrated the run-to-run stability of the misalignments to be very small (about 1 mil - 3 arc minutes) as seen in Figure 11.

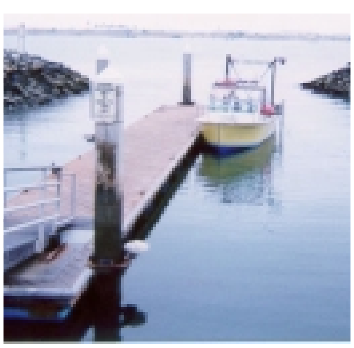


Figure 8. Initial Testing Vessel in San Diego Bay

Test results on a surface vessel using inertial and DVL inputs (compared to a DGPS reference) demonstrated about 0.1% distance traveled. Application to an underwater vehicle with less vehicle dynamics (wave action causing noise in the DVL measurements) should improve accuracy significantly. A typical installation of SEA*DeViL* is shown in Figure 10.

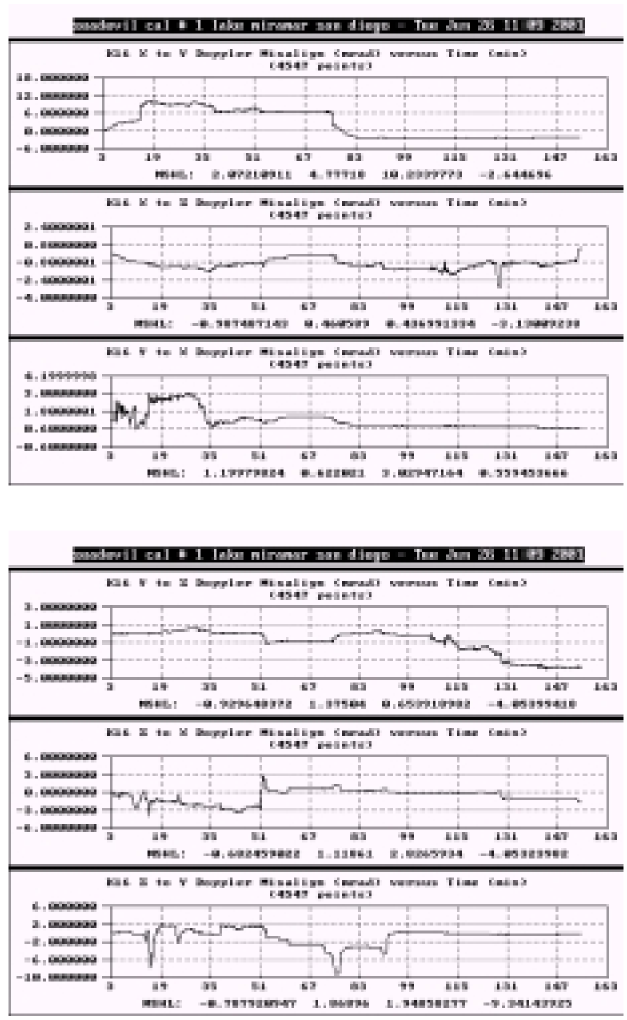


Figure 9. Misalignment Calibration (10 Mil)

Figure 10. SEA*DeViL* Installed in ALTEX UUV

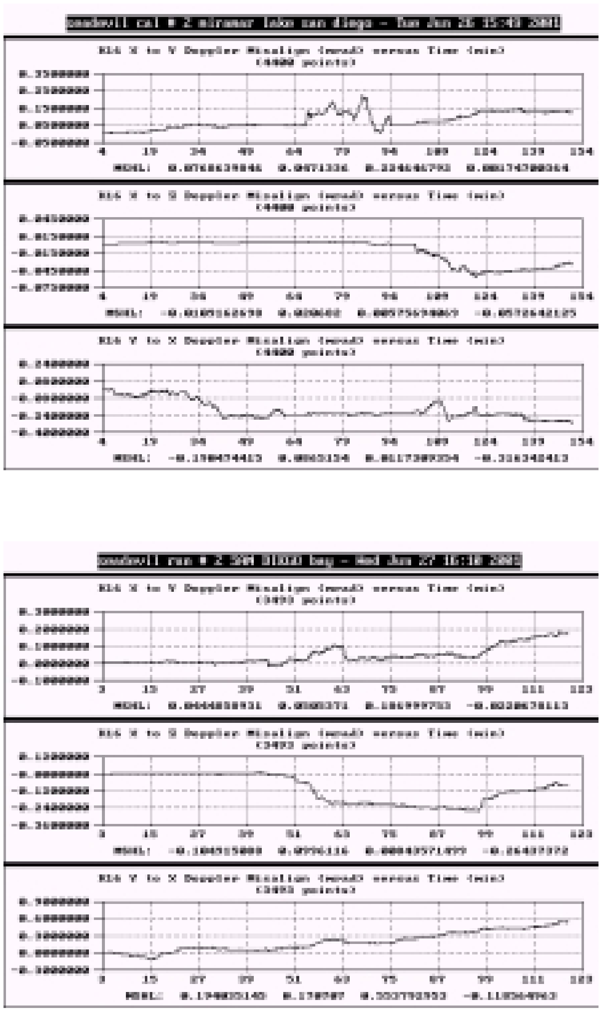


Figure 11. Misalignment Calibration (1 Mil)

Test results at high latitude (82 degrees as seen in Figure 12.) show the ability to accomplish moving base alignment to north with an estimated heading error of less than 2 mils utilizing GPS position and velocity observations while the vehicle is on the surface as seen in Figure 13. This was confirmed by discontinuing the availability both GPS and DVL information to the Kalman Filter and operating SEA*DeViL* in a free inertial mode for about 1 hour. Position and velocity errors were consistent with the quality of the SEA*DeViL* inertial sensor (if it was statically aligned at mid latitude - < 1 nm/hr).

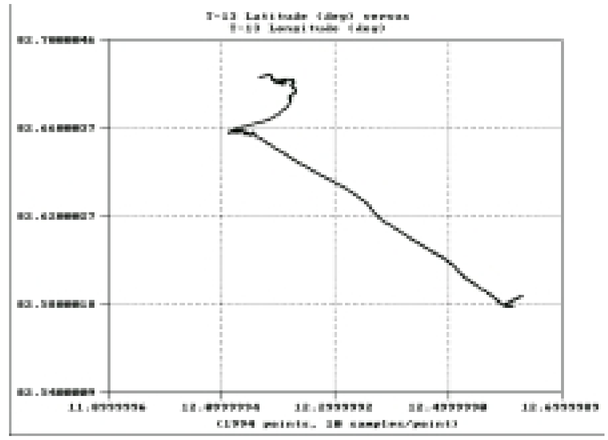


Figure 12. High Latitude Performance

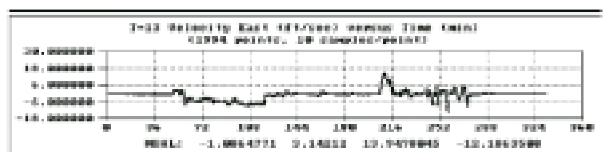


Figure 13. Velocity, High Latitude Performance

CONCLUSION

The SEA*DeViL* system fulfills the need for a compact, integrated INS/DVL/GPS for a multitude of maritime guidance applications. Kearfott's MRLG and a compact ISA allow for the significant reduction in size, weight, and power necessary for a maritime navigation system. RDIs' DVL allow for high accuracy position and heading for extended operation underwater without GPS aiding. Coupled with a GPS/DGPS receiver, the system performance provides a self-contained highly accurate position, velocity and attitude information for an indefinite period of time

ACKNOWLEDGEMENTS

The following individuals are gratefully acknowledged as contributors to the preparation of material presented.

Donald J. Weber	-	Kearfott
Frank Psota	-	Kearfott
Irwin Goldman	-	Kearfott
Graham Lester	-	RDI
John Romeo	-	RDI
Hans Thomas	-	MBARI