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Monterey, California



THESIS

**HARDWARE INTEGRATION OF THE SMALL
AUTONOMOUS UNDERWATER VEHICLE NAVIGATION
SYSTEM (SANS) USING A PC/104 COMPUTER**

by

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March 1999

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UNDERWATER VEHICLE NAVIGATION SYSTEM (SANS) USING A
PC/104 COMPUTER**

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Lieutenant Junior Grade, Turkish Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

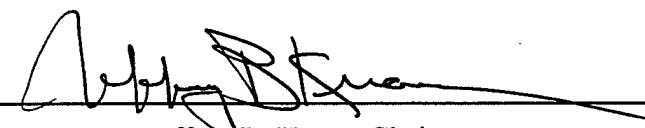
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**NAVAL POSTGRADUATE SCHOOL
March 1999**

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ABSTRACT

At the Naval Postgraduate School (NPS), a small AUV navigation system (SANS) has been developed for research in support of shallow-water mine countermeasures and coastal environmental monitoring. The objective of this thesis is to develop a new version of SANS, aimed at reducing size and increasing reliability by utilizing state-of-the-art hardware components.

The new hardware configuration uses a PC/104 computer system, and a Crossbow DMU-VG Six-Axis Inertial Measurement Unit (IMU). The PC/104 computer provides more computing power and more importantly, increases the reliability and compatibility of the system. Replacing the old IMU with a Crossbow IMU eliminates the need for an analog-to-digital (A/D) converter, and thus reduces the overall size of the SANS.

The new hardware components are integrated into a working system. A software interface is developed for each component. An asynchronous Kalman filter is implemented in the current SANS system as a navigation filter. Bench testing is conducted and indicates that the system works properly. The new components reduce the size of the system by 52% and increase the sampling rate to more than 80Hz.

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DEDICATION

For my mother and wife

I. INTRODUCTION

A. BACKGROUND

An Autonomous Underwater Vehicle (AUV) can be capable of numerous missions, both overt and clandestine. Such vehicles have been used for inspection, mine countermeasures, survey, and observation [Ref. 1]. One of the most important and difficult aspects of an AUV mission is navigation. In order to achieve a wide variety of missions, the navigation system of the AUV must be accurate. AUV navigation may be accomplished using the Global Positioning System (GPS) and an Inertial Navigation System (INS). GPS is capable of supplying accurate navigation, if it is integrated with INS to compensate for the loss of GPS signals due to environmental blockages. GPS provides accurate positioning when the AUV is surfaced, while the INS is used for submerged navigation.

At the Naval Postgraduate School (NPS), a Small AUV Navigation System (SANS) has been developed for research in support of shallow-water mine countermeasures and coastal environmental monitoring [Ref. 2]. The goal of designing this system is to demonstrate the feasibility of using a small, low-cost Inertial Measurement Unit (IMU) to navigate between Differential Global Positioning System (DGPS) fixes.

The current version of SANS is composed of "off the shelf" components, which include an IMU, GPS/DGPS Receiver, magnetic compass, water speed sensor, and data processing computer.

An asynchronous Kalman Filter, which has six states for orientation estimation, and eight states for position estimation, is used in the system as navigation software. The SANS system has been upgraded using an AMD 586DX133 based PC/104 computer to provide more computing power and more importantly to increase reliability and provide compatibility with PC/104 industrial standards. [Ref. 3]

The goal of this thesis is to contribute to the ongoing AUV research project at NPS by integrating hardware and software of the INS/GPS navigation system using an AMD 586DX133 based PC/104 computer.

B. RESEARCH QUESTIONS

This thesis will examine the following research areas:

- Integrate an AMD 586DX133 based PC/104 computer into the SANS system.
- Develop the software interface, which will communicate between GPS receiver, compass, IMU and, processing computer.
- Implement the asynchronous Kalman filter developed by reference [3] into the new hardware system.
- Test and evaluate the hardware and software.

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

This thesis reports part of the findings of more than seven years of research in an ongoing project. The main scope of this thesis is to integrate an AMD 586DX133 based PC/104 computer into the SANS system to provide more computing power and, more importantly, to increase reliability and computability.

D. ORGANIZATION OF THESIS

Chapter II provides a detailed description of the hardware components and system integration.

Chapter III describes the software additions, and changes to support current hardware configurations.

Chapter IV presents testing results of the system.

Chapter V presents the thesis conclusions and provides recommendations for future research.

II. SANS HARDWARE CONFIGURATION

A. INTRODUCTION

Previous versions of the SANS hardware configuration are described in References [4,5,6,7, and 8]. The purpose of this chapter is to present detailed information about the current SANS hardware configuration and operation. Most of the previous SANS hardware parts have been replaced with more powerful, more flexible, and more reliable components which are faster, smaller, and cheaper.

Figure 2.1 shows the current SANS hardware configuration. The main hardware components are the Crossbow DMU-VG Six Axis IMU, the Oncore GPS/DGPS Receiver, the Precision Navigation TCM2 Electronic Compass, the SonTek Hydra Water Speed Sensor, the Sealevel C4-104 Serial I/O Module, and the AMD 586DX133 based PC/104.

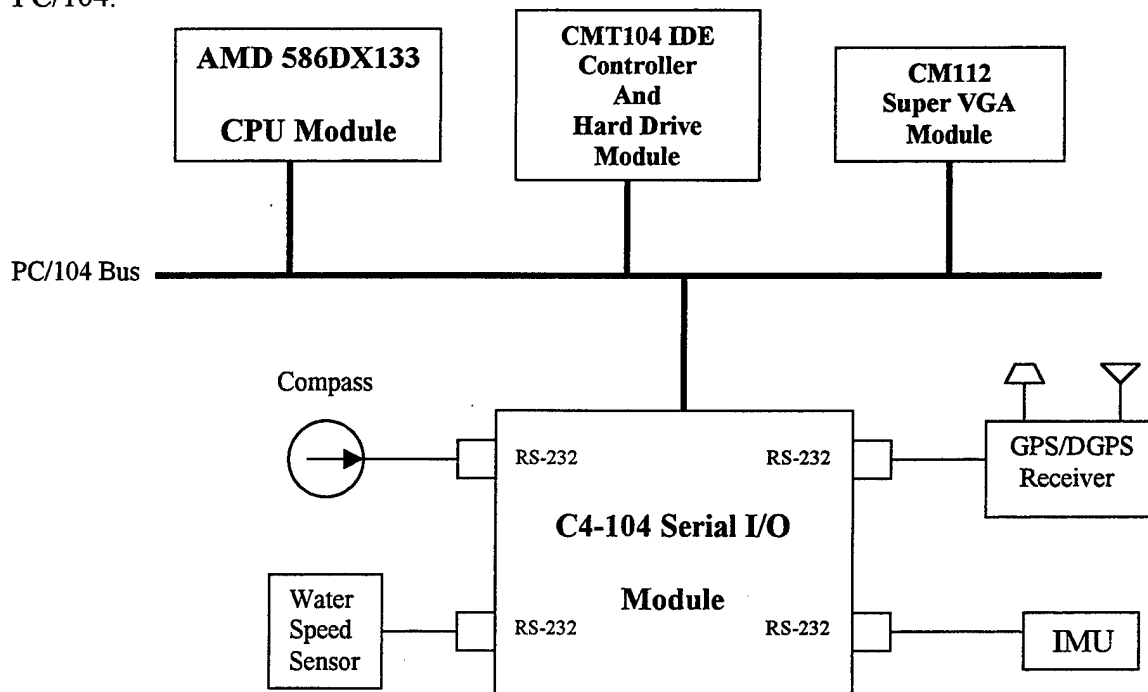


Figure 2.1: Current SANS Hardware Configuration

B. **HARDWARE DESCRIPTION**

1. Precision Navigation TCM2 Electronic Compass

The Precision Navigation model TCM2 Electronic Compass Module is used in the current SANS hardware configuration. The TCM2 consists of a three-axis magnetometer, a two-axis tilt sensor and a small A/D board. Output includes roll, pitch, heading, and a three dimensional magnetic field measurement. It is accurate to within one half of a degree in level operation. The TCM2 will provide more accurate heading information following calibration (performed by user) for local magnetic field distortions. It provides an alarm when local magnetic anomalies are present, and gives out-of-range warnings when the unit is being tilted too far. The calibration of the compass and its error characteristics are described in [Ref. 6]. It requires 5 VDC and 15-22 mA [Ref. 9].

2. Real Time Devices AMD 586DX133 Based PC/104

The Real Time Devices AMD 586DX133 based PC/104 is employed as a data acquisition and processing unit in the current version of the SANS system. PC/104 is an industrial standard for PC-compatible modules that can be stacked together to create embedded computer applications. This system fulfills the basic needs of embedded systems such as low power consumption, modularity, small foot print, high reliability, good noise immunity, high speed operation, and expandability.

The PC/104 can be easily customized by stacking PC/104 modules that are compliant with the PC/104 bus architecture, such as video controllers, network interfaces, analog and digital data acquisition modules, sound I/O modules etc.

The SANS system is equipped with four PC/104 modules. These are the AMD 586DX133 CPU Module, the CMT104 IDE Controller and Hard Drive Module, the CM112 Super VGA Module, and the C4-104 Serial I/O Module.

The PC/104 CPU module offers all major functions of a standard PC computer on one compact board. Figure 2.2 shows a simplified block diagram of the PC/104 CPU module. It has all primary I/O functions of a standard PC computer including a keyboard interface, a parallel port, two serial ports, a Real Time Clock, and a speaker port. It also enhances standard PC compatible computer systems by adding: Solid State Disk sockets, a non-volatile configuration EEPROM, and a Watchdog Timer [Ref. 10].

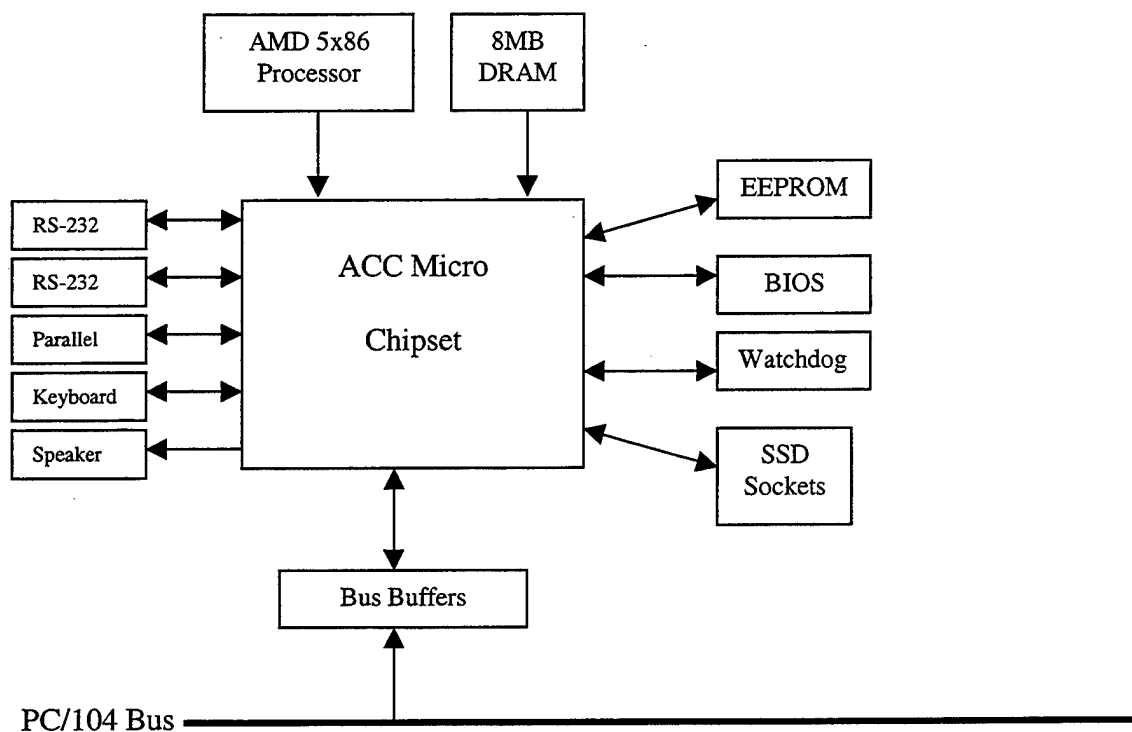


Figure 2.2: PC/104 CPU Module

The CMT104 IDE Controller and Hard Drive Module were designed to integrate IDE hard drive or Flash Drive in the PC/104 stack to support the CPU module. It allows up to four drives in the system. [Ref. 11]

The CM112 Super VGA Module was designed to provide Super VGA video, as well as floppy and hard drive support for the CPU module. Super VGA has a resolution of up to 1024 x 768 pixels with at least 256 colors. [Ref. 12]

The PC/104 is implemented with PC compatible BIOS, which supports the ROM-DOS and MS-DOS operating systems. Drivers in the BIOS can boot from the floppy disk, hard disk, Solid State Disk (SSD), or a serial port link. [Ref. 10]

The system uses an AMD Am5x86 microprocessor with 133Mhz. clock speed. It's physical dimensions are 3.6 x 3.8 x 0.6 inches (97 x 100 x 16 mm) and its weight is 3.4 ounces (100 grams). It operates on 5 VDC +/- 5%. Power consumption depends on the peripherals connected to the board, the selected SSD configuration, and the memory configuration. The power consumption for typical configurations is 1.75 A (8.75 W). The PC/104 CPU module has a 12MB (expandable to 72MB) disk on chip that will store the SANS code and any other data it uses. An integral Viper 170MB hard drive on the CMT104 Hard Drive Module is also available for more data storage. [Ref. 10]

3. Sealevel C4-104 Serial I/O Module

The SANS system uses four serial port connections for the sensors. These are the IMU, DGPS, compass, and water speed sensor. Two serial ports usually come standard on PCs. The Sealevel C4-104 serial I/O module provides four RS-232 serial I/O ports for the PC/104 application. Each serial port has its own base memory addresses and

Interrupt Request (IRQ) assignments. Table 2.1 shows the base address and IRQ setting used with SANS. The address and IRQ selection options are described in Reference [13].

	Base Address (hex.)	IRQ
Port 1	3F8	4
Port 2	2F8	3
Port 3	3E8	5
Port 4	2E8	3

Table 2.1: The base address and IRQ settings [Ref. 13]

The C4-104 is compliant with PC/104 specification including both mechanical and electrical specifications. The C4-104 utilizes 6554 Universal Asynchronous Receiver/Transmitters (UART) with programmable baud rates, data format, interrupt control and a 16-byte input and output FIFO. The system operates on 5 volt DC. [Ref. 13]

4. Crossbow DMU-VG Six Axis Inertial Measurement Unit

The DMU-VG (Figure 2.3) is a six-axis measurement system designed to measure linear acceleration along three orthogonal axes, and rotation rates around three orthogonal axes. It is designed to provide stabilized pitch and roll in dynamic environments [Ref. 14]. The IMU has both analog output and RS-232 serial port output. Previous versions of SANS were equipped with a Systron Donner MotionPak IMU, which delivered data only in analog format. Thus, replacing the MotionPak IMU with the Crossbow DMU-VG IMU eliminated the need for a PC/104 A/D module, and therefore reduced the total size of the SANS unit. The general specifications of the DMU-VG are shown in Table

2.2 and the structure of the data packet sent over the RS-232 interface is shown in Table 2.3.

Chapter III presents more detailed information about Crossbow DMU-VG IMU interface.

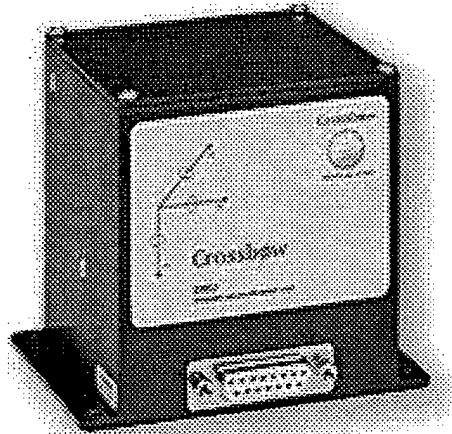


Figure 2.3: Crossbow DMU-VG [Ref. 14]

Parameter	Units	Range
Roll Range	deg.	-/+ 180
Pitch Range	deg.	-/+ 90
Roll, Pitch Angle: Dynamic Accuracy	deg. RMS	1
Roll, Pitch Angle: Repeatability	deg.	0.5
Roll, Pitch, Yaw Angular Rate Resolution	deg./sec.	0.05
Bandwidth	Hz.	10
Input Supply Voltage	Volt. DC.	8 – 30
Input Supply Current	mA(max.)	100
Package	Inches	3 x 3.375 x 3.250
Weight	Grams	475
Operating Temperature Range	degrees C.	40 to 85

Table 2.2: Crossbow IMU Specifications [Ref. 15]

Note: Most Significant Bit (MSB) Least Significant Bit (LSB)

Byte	D M U - V G
0	Header (255)
1	Roll (MSB)
2	Roll (LSB)
3	Pitch (MSB)
4	Pitch (LSB)
5	Roll Rate X (MSB)
6	Roll Rate X (LSB)
7	Pitch Rate (MSB)
8	Pitch Rate Y (LSB)
9	Yaw Rate Z (MSB)
10	Yaw Rate (LSB)
11	Acceleration X (MSB)
12	Acceleration X (LSB)
13	Acceleration Y (MSB)
14	Acceleration Y (LSB)
15	Acceleration Z (MSB)
16	Acceleration Z (LSB)
17	Temp Sensor Voltage (MSB)
18	Temp Sensor Voltage (LSB)
19	Time (MSB)
20	Time (LSB)
21	Checksum

Table 2.3: Crossbow IMU Data Packet Format [Ref. 15]

5. Motorola Oncore GPS/DGPS Receiver

The GPS receiver used in the SANS system is the Motorola ONCORE Receiver. It is capable of tracking eight satellites simultaneously. The GPS receiver incorporates a DGPS capability. It operates on a 5 volt DC regulated power source. It's data port interface is RS-232 compatible. The output message consists of latitude, longitude, height, velocity, heading, time, and satellite tracking status. It can provide position accuracy of better than 25 meters Spherical Error Probable (SEP) with Selective

Availability (SA) and 100 meters SEP without SA. The typical Time-To-First-Fix (TTFF) is 18 seconds with a 2.5 second reacquisition time [Ref. 16].

6. SonTek Hydra Water Speed Sensor

The SonTek Hydra Water Speed Sensor is a single point, high resolution, 3D Doppler current meter. It measures the velocity of water using the Doppler effect. The device uses one transmitter and 3 acoustic receivers, which are aligned to intersect with the transmitted beam pattern. The velocity measured by each receiver is referred to as the bistatic velocity, and is the projection of the 3D velocity vector onto the bistatic axis of the acoustic receiver. The bistatic velocities are converted to XYZ velocities. The velocity data can be reported as the data in an Earth (North-East) fixed coordinate system by using compass and tilt sensors. The sensor provides data over a RS-232 serial port interface. [Ref. 17]

The general specifications of the system are presented in Table 2.4.

Parameter	Units	Range
Acoustic frequency	MHz.	5
Range (programmable)	cm/sec.	-/+ 5, 20, 50, 200, 500
Velocity resolution	mm/sec.	0.1
Sampling rate	Hz.	0.1 – 25
Internal recorder	Mbytes	20
Operating temperature	deg. C	-2 – 40
Power supply	Volt DC.	12 – 24
Power consumption	W	2.5 – 5
Max. deployment depth (Delrin)	m	250
Max. deployment depth (Stainless steel)	m	2000

Table 2.4: Hydra Water Speed Sensor Specifications [Ref. 17]

C. FUTURE COMPONENTS

For future SANS hardware configurations, a Local Area Network (LAN) connection to transmit data from SANS to a host processor is desired. In order to meet this need, the addition of Proxim Range LAN2 PC card to the system is being considered. The Range LAN2 system is capable of transmitting data at 1.6Mbps. through a PCMCIA card format at distances up to 1000 feet [Ref. 18]. This card provides the ability to observe data received from the sensors remotely.

The technological advances in GPS area make it possible change out the four year old DGPS package. Two possible products, Rockwell Semiconductor's NAVCAR LP, and Trimble's Pathfinder with ASPEN software, are being considered. With this feature, more accurate navigation information could be acquired, as well as smaller size advantages.

D. SUMMARY

The components in the current SANS hardware configuration were chosen based on size, cost, power, and ease of operation. The current SANS configuration uses a Crossbow DMU-VG Six Axis IMU, a C4-104 Serial I/O Module, and an AMD 586DX133 based PC/104 computer.

The new components reduced the size of the system by 52% [Ref. 3]. The new IMU unit provided both analog and digital data output. Thus, the need for a PC/104 A/D module was eliminated. The C4-104 Serial I/O Module provided four RS-232 serial ports for the PC/104 application. The AMD 586DX133 based PC/104 computer provided more computing power and, more importantly, increased reliability and

compatibility with PC/104 industrial standards [Ref. 3]. Testing and the evaluation of the new SANS hardware configuration is currently in progress.

III. SOFTWARE DEVELOPMENT

A. INTRODUCTION

The purpose of the SANS software is to utilize IMU, heading, and water-speed information to implement an INS based on an asynchronous Kalman filter. The INS information is integrated with GPS information to obtain continuously accurate navigation information in real time.

Changes in the SANS hardware configuration have driven subsequent changes in the software design. The previous version of SANS used two serial ports to obtain data using a RS-232 interface. The GPS data was received via the COM1 serial port, and the compass data was received via the COM2 serial port. The previous IMU sensor provided data in analog format. Additional code was required in the SANS software to operate the A/D converter module and buffer this data.

In the current version of SANS, a Sealevel C4-104 module provides four serial port connections. The previous IMU has been replaced with a Crossbow DMU-VG six-axis measurement unit, which outputs digital data over RS-232. Thus, the software developed for the current version of SANS has four serial port data communication objects to acquire data from sensors. COM1 is assigned to the GPS, COM2 is assigned to the compass, COM3 is assigned to the IMU, and COM4 is assigned to the water speed sensor.

The constant-gain filter used in the previous version of SANS was replaced with an asynchronous Kalman filter, which has six states for orientation estimation, and eight states for position estimation.

The software was implemented in C⁺⁺ and compiled using the Borland 5.0 compiler. It is designed to run on a standard DOS platform for use on an AMD586DX/133 MHz processor.

B. SOFTWARE DESCRIPTION

The current implementation of the SANS software continues to be based on the software described in reference [4]. The software changes and additions to support current SANS hardware are introduced in this chapter. Figure 3.1 shows the SANS software objects and data flow. Source code for these objects can be found in Appendix A and B.

1. GPS Data

The GPS class object obtains GPS position messages in the Motorola 8-Channel Position/Status/Data Output Message (@@Ea) format. The code to process GPS information is slightly different from that described by reference [7].

The GPS message is received over RS-232 interface via COM1 serial port. The message length of 8-channel GPS data is 76 bytes long. The GPS object instantiates the GPS buffer and the serial port object, which communicates with the GPS receiver. The GPS object checks for the arrival of new messages. Before the GPS object recognizes a message as valid, the message must pass the conditions below:

- The message should have the proper header for the Motorola position message format.
- The message has a valid checksum.
- The number of satellites tracked must be at least three.

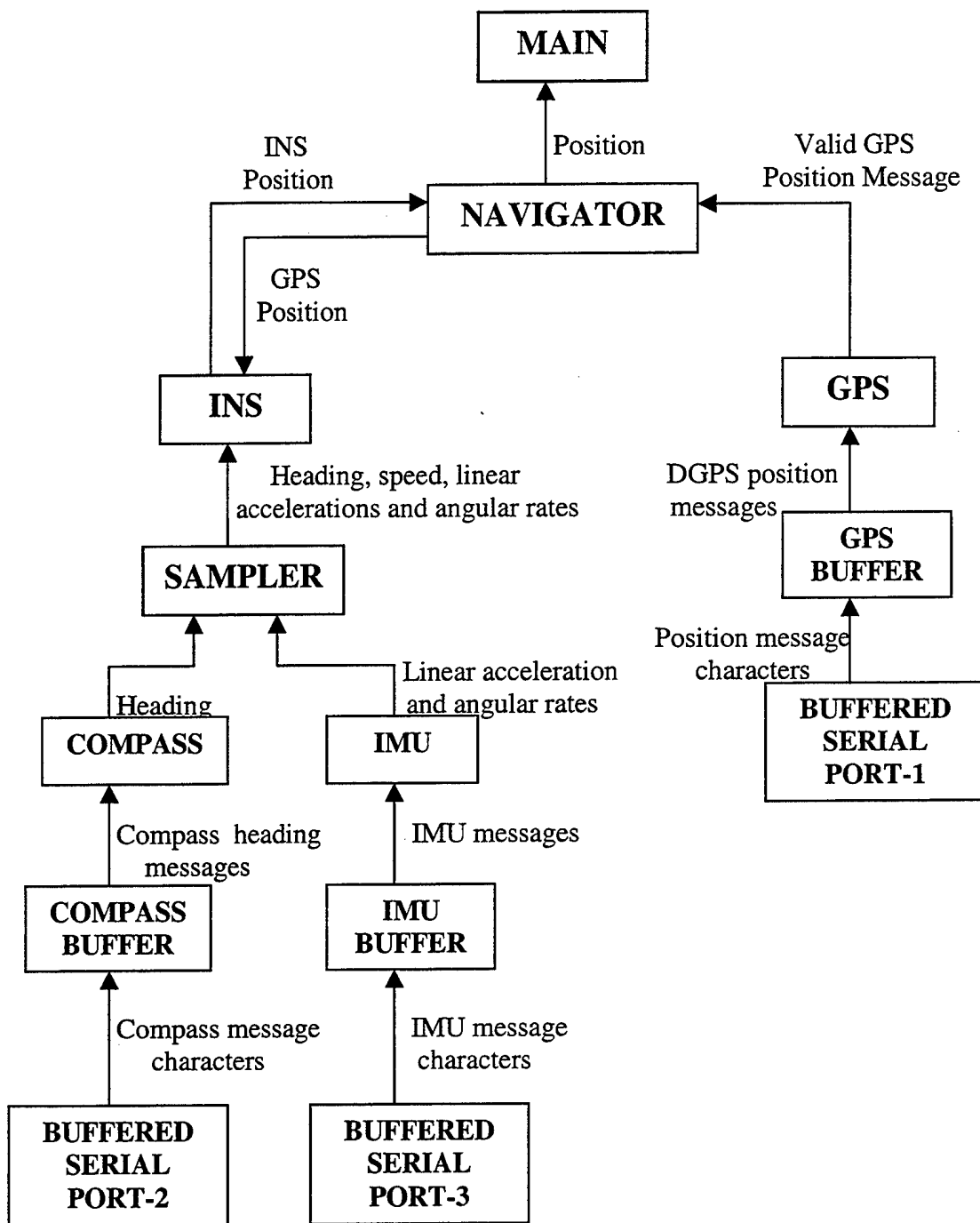


Figure 3.1 SANS Software Objects and Data Flow

- The differential receiver status message bit in GPS message must be set.

If one of these conditions fails, the message is considered invalid.

2. Compass Data

The compass data is received over RS-232 interface via the COM2 serial port. The code to acquire compass data is the same as described in reference [7]. The object instantiates the compass buffer and serial port objects needed to communicate with the compass. The message length for compass data is 60 bytes long. When a compass message is received at the communications port, the code checks the checksum and the header. If one of these checks fails, the message is considered invalid and is ignored.

3. IMU Data

The IMU data is received over RS-232 interface via the COM3 serial port. The IMU object instantiates the IMU buffer and serial port objects needed to communicate with the Crossbow DMU-VG IMU. Each data packet of the IMU begins with a header byte, and ends with a checksum. When an IMU message arrives at the communication port, the code checks the header, and calculates the checksum and compares it to the checksum of the data packet. If one of these checks fails, the message is considered invalid and is ignored.

The Crossbow DMU-VG IMU can operate in one of three modes: voltage mode, scaled sensor mode, or VG mode. The SANS system uses VG mode. The IMU data packet format for VG mode is shown in Table 2.3. The message has 22 bytes of data. The data packet consists of stabilized pitch and roll angles along with angular rate and linear acceleration information.

The digital data is received as a 16-bit number (two bytes). The MSB of the data is received first, followed by the LSB. This digital data can be converted into a single number using the following equation:

$$\text{value} = \text{MSB} \times 256 + \text{LSB} \quad (3.1)$$

The acceleration data (x, y, and z) in data packet is converted into G's (gravity). The digital data is first converted into a single number using equation (3.1). Then, the following equation is used:

$$\text{acceleration} = \text{value} \times (\text{GR} \times 1.5) / 2^{15} \quad (3.2)$$

“GR” is the G range of the IMU unit. It is 2G for the IMU used in the SANS system.

The angular rate data (roll, pitch, and yaw rate) in the data packet is converted into degrees per second. The digital data is first converted into a single number using equation (3.1). Then, the following equation is used:

$$\text{angular rate} = \text{value} \times (\text{AR} \times 1.5) / 2^{15} \quad (3.3)$$

“AR” is the angular rate range of the IMU unit. It is 50 degrees per second for the IMU used in the SANS system.

The IMU has a simple command structure. A command consisting of one or two bytes can be sent to the sensor over the RS-232 interface. Table 3.1 shows the DMU-VG six-axis IMU command sets.

4. INS

The INS class implements the inertial navigation portion of the SANS using the asynchronous Kalman filter. The INS class instantiates a Sampler object from which it obtains heading, speed, linear acceleration data, and angular rate data. GPS information is also passed to the INS class via Navigator object.

Command (ASCII)	Response	Description
R	H	Reset: Resets the DMU
G	Data Packet	Get Data: Requests a packet of data from The DMU.
r	R	Change to Voltage Mode
c	C	Change to Scaled Sensor Mode
a	A	Change to VG output Mode
T<0-255>	None	2 byte command sequence that changes the vertical gyro erection rate.
C	None	Change to continuous data transmit mode. Data packets streamed continuously.
P	None	Change to polled mode. Data packets sent when G is received by the DMU.
z<0-255>	Z	Calibrate and set zero bias rate sensors by averaging over time. 1 st byte initiates zeroing process. 2 nd byte sets duration for averaging.

Table 3.1 IMU Command Sets [Ref. 19]

The INS produces accurate navigation information by integrating IMU data and DGPS data. While IMU data is sampled continuously, DGPS data is available only aperiodically due to asynchronous reacquisition of satellite signals and asynchronous submergence of the AUV. Asynchronous Kalman filtering is an ideal method to obtain accurate navigation information. [Ref. 3]

Figure 3.2 presents a data flow diagram of the SANS navigation filter. The asynchronous Kalman Filter has six states for orientation estimation, and eight states for position estimation. The orientation estimation part of the filter remains the same as described in reference [6] and will not be presented here.

The position estimation part of the filter uses the measurement of the velocity relative to water provided by the water speed sensor and position information provided by DGPS. The velocity measurements are synchronous and available at every sampling interval. DGPS information is asynchronous and is only available when the AUV is surfaced.

The Kalman filter is a recursive predictive update technique used to estimate the states of a process model. Given some initial estimates, it allows the states of a model to be predicted and adjusted with each new measurement.

The filter contains five recursive equations. The Kalman filter gain (K_k) is needed to find the optimal estimated states ($\hat{x}_k$). It takes the error covariance (mean-square error) between the current state x_k and the estimated state $\hat{x}_k$ and applies it to the H and R matrixes resulting in

$$K_k = P_k^{-1} H^T (H P_k^{-1} H^T + R)^{-1} \quad (3.4)$$

Beginning with a prior estimate $\hat{x}_k^-$, the noisy measurement z_k is used with a blending factor K_k to improve the estimate as follows;

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - H \hat{x}_k^-) \quad (3.5)$$

The vector x_k consists of eight states which are the north position, east position, north velocity, east velocity, north current, east current, north GPS bias, and east GPS bias.

Once the Kalman gain K_k minimizes the mean-square estimation error, the error covariance matrix for $\hat{x}_k$ can be computed using the equation below;

$$P_k = (I - K_k H) P_k^- \quad (3.6)$$

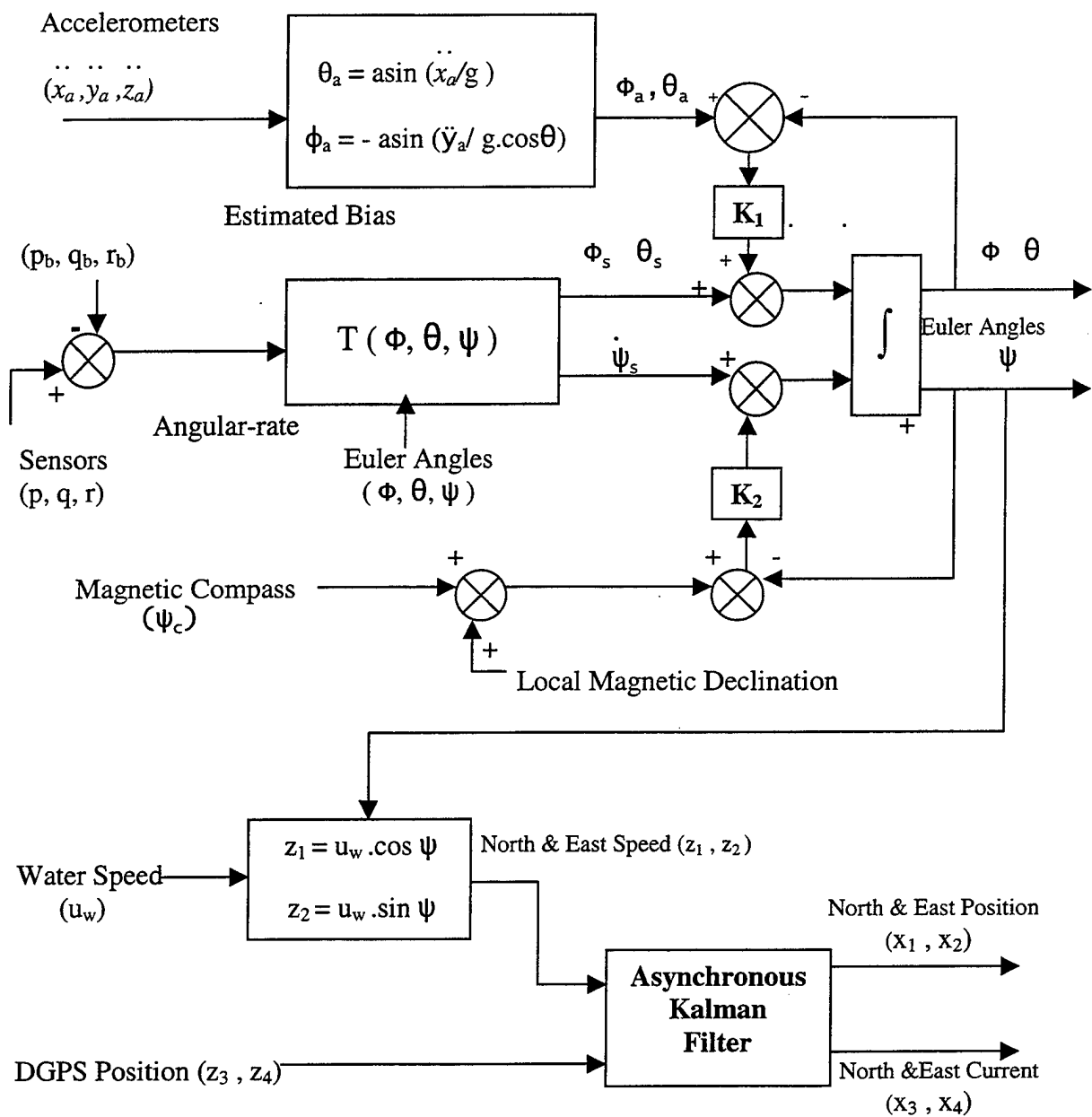


Figure 3.2 SANS Navigation Filter

The updated estimate $\hat{\mathbf{x}}_k$ is projected ahead using the state transition matrix ϕ .

Thus,

$$\hat{\mathbf{x}}_{k+1}^- = \phi \hat{\mathbf{x}}_k \quad (3.7)$$

Finally, the projected error covariance for $\hat{\mathbf{x}}_{k+1}^-$ can be calculated as follows:

$$\mathbf{P}_{k+1}^- = \phi \mathbf{P}_k \phi^T + \mathbf{Q}_k \quad (3.8)$$

Equations (3.4 – 3.8) are used as an algorithm that loops infinitely. This Kalman filter loop is shown in Figure (3.2).

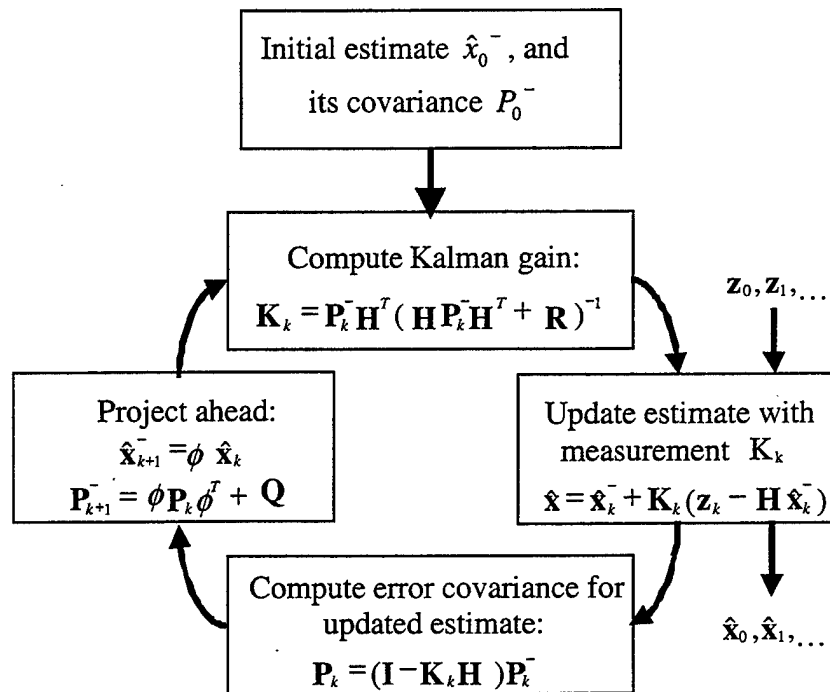


Figure 3.3 Kalman Filter Loop [Ref. 3]

The state transition matrix ϕ can be calculated as follows;

$$\phi = \begin{bmatrix} e^{\frac{-|\Delta|}{\tau_1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & e^{\frac{-|\Delta|}{\tau_1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & e^{\frac{-|\Delta|}{\tau_2}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & e^{\frac{-|\Delta|}{\tau_2}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & e^{\frac{-|\Delta|}{\tau_3}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & e^{\frac{-|\Delta|}{\tau_3}} & 0 & 0 \\ \tau_1 \left(1 - e^{\frac{-|\Delta|}{\tau_1}} \right) & 0 & \tau_2 \left(1 - e^{\frac{-|\Delta|}{\tau_2}} \right) & 0 & 0 & 0 & 0 & 0 \\ 0 & \tau_1 \left(1 - e^{\frac{-|\Delta|}{\tau_1}} \right) & 0 & \tau_2 \left(1 - e^{\frac{-|\Delta|}{\tau_2}} \right) & 0 & 0 & 0 & 0 \end{bmatrix}$$

The next item needed for the Kalman filter was the $\mathbf{Q}_k$ matrix.

$$\mathbf{Q}_k = \begin{bmatrix} \frac{1}{2\tau_1} \left(1 - e^{-\frac{2\Delta t}{\tau_1}} \right) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2\tau_1} \left(1 - e^{-\frac{2\Delta t}{\tau_1}} \right) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2\tau_2} \left(1 - e^{-\frac{2\Delta t}{\tau_2}} \right) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2\tau_2} \left(1 - e^{-\frac{2\Delta t}{\tau_2}} \right) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2\tau_3} \left(1 - e^{-\frac{2\Delta t}{\tau_3}} \right) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{2\tau_3} \left(1 - e^{-\frac{2\Delta t}{\tau_3}} \right) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The measurement error covariance $\mathbf{R}$ is estimated as;

$$\mathbf{R} = \begin{bmatrix} .5 & 0 & 0 & 0 \\ 0 & .5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \text{ with DGPS signal}$$

or

$$\mathbf{R} = \begin{bmatrix} .5 & 0 \\ 0 & .5 \end{bmatrix} \text{ without DGPS signal}$$

The matrix $\mathbf{H}$ is the ideal (noiseless) connection between the measurements and the state vector at time t . Two $\mathbf{H}$ matrices describe this connection, one for samples with DGPS the other for samples without DGPS.

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} \text{with DGPS signal}$$

or

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{without DGPS signal}$$

5. Sampler

The Sampler prepares raw IMU, heading and water speed data for use by the INS object. The Sampler controls the data formatting and returns a formatted sample if valid raw IMU data is available. Otherwise, a negative response is returned.

The sampler instantiates the IMU object from which it obtains IMU data packets as shown in Table 2.3. The data received from the IMU is signed 16 bit 2's complement integers. The sampler object first uses equation (3.1) to obtain single numbers. If the number is greater than $32767 (2^{15}-1)$, it subtracts $65536 (2^{16})$ from the number to get the correct sign. After this operation, the sampler object formats the linear acceleration and angular rate data using equations (3.2) and (3.3).

The sampler object also calculates the time delta (Δt) using the IMU clock. The IMU time data is presented in the 19th and 20th bytes of the IMU data packet. The IMU clock counts down from 65535 to 0. A single tick corresponds to 0.79 microseconds [Ref. 15]. The sampler uses the following equation to calculate Δt :

$$\Delta t = 0.79 \times 10^{-6} \times \text{time difference} \quad (3.9)$$

where "time difference" is calculated by subtracting the current IMU time from the previous one.

The sampler object also instantiates the compass object from which it obtains heading information. The compass object is unchanged from that described in Reference [7].

6. Navigator

The navigator object instantiates both GPS and INS objects and provides an estimate of the current position in hours, minutes, seconds and milliseconds of latitude and longitude. The navigator object is invoked by the main object. The navigator object interfaces with the GPS and INS objects to determine if they have an updated estimate of the current position. If GPS information available, the navigator object converts a latitude and longitude expressed in milliseconds to a grid position in feet and passes it to INS class, so that the INS object can calculate the current position estimate with new GPS information. If no GPS information is available, the INS object calculates the current position estimate without GPS fixes. If the navigator object obtains an updated grid position from the INS, it converts the information to degrees, minutes, seconds and milliseconds and returns this as the current estimated position. If no updated INS information is available, the navigator returns a negative reply indicating that there is no updated position estimate.

C. SEALEVEL C4-104 I/O MODULE SOFTWARE

The C4-104 module provides four RS-232 serial ports, utilizing a 16554 UART. A UART contains seven functional registers that are used for reporting the ports' status and for initializing the communication parameters under which the serial port will

function. In order to access to these registers, the DOS operating system reserves locations in memory which hold the base address for the UART associated with COM1-COM4.

The SETCOM program is a special program provided by manufacturer for the C4-104 module. It can be used to set COM1-COM4 address and communication parameters. This program initializes the COM port addresses. It also sets the baud rate and other parameters needed to communicate. The baud rate can be set up to values as high as 115.2 K baud.

The syntax of the SETCOM program is given below;

SETCOM A, BBB, CCCC, D, E, F

where, A is the COM port number to be set (1-4), B is the Hex Address of the COM port, C is the baud rate (300,600,1200,4800,9600,19.2,38.4,57.6,115.2), D is the parity (N for no parity, E for even parity, and O for odd parity), E is the word length in bits (5,6,7,8), and F is stop bits (1,2).

As an example to set COM1 to address 2F8 Hex, 19.2 K baud rate, no parity, 7 bit word, and 1 stop bit, the SETCOM command would be;

SETCOM 1, 2F8, 19.2, N, 7, 1

When the PC is first started, the communication ports are initialized using SETCOM program. The SETCOM program settings for the SANS are shown in Table 3.2. The SETCOM program is put in the "autoexec.bat" file of computer, so that each time the PC is started, it can set the ports automatically.

Port No	Adress (hex)	Baud Rate	Parity	Word Length (bit)	Stop Bits
1	3F8	9600	No Parity	8	1
2	2F8	9600	No Parity	8	1
3	3E8	38400	No Parity	8	1
4	3E8	9600	No Parity	8	1

Table 3.2 SETCOM Program Settings for Serial Port

D. SUMMARY

All additions and updates to the SANS software were compiled under the Borland version 5.0, C++ compiler. The software runs on a DOS (standard) platform with an AMD 586DX/133 MHz processor.

Significant as well as minor changes have been made in the SANS software. The IMU data is now received from a serial port. Replacing the previous unit with the new IMU eliminated the need for additional code to operate the A/D converter module, and buffers this data. The compass data and GPS data are also received via serial ports. The code to acquire water speed sensor data is currently under development.

Since DGPS information is available aperiodically due to asynchronous reacquisition time of satellite signals and asynchronous submergence and surfacing duration of the AUV, an asynchronous Kalman filter is needed to optimally integrate IMU and DGPS data. The previous SANS constant-gain filter is now replaced by an asynchronous Kalman filter. This filter has six states for orientation estimation (still constant gain), and eight states for position estimation.

A complete copy of all SANS software is presented in Appendix A and B.

IV. SYSTEM TESTING

A. INTRODUCTION

This chapter presents the bench testing of the current SANS configuration. After integrating the new hardware and implementing the new software, bench testing was performed to determine the functionality and accuracy of the entire system. Simulation results of the SANS Kalman filter are presented in the following section. The system was tested with different speed and different heading information.

B. BENCH TESTING

The system was tested with north heading and east heading information, and position versus time plotting was presented. For bench testing, water speed sensor was simulated by applying different voltages to the system for different speed information. The speedometer developed in reference [6] was utilized in previous versions of the SANS to measure the speed of the system. In order to simulate a speedometer for the bench testing, the following equation was used to convert voltage (V) into speed (v):

$$v = \frac{-7.64}{V} \quad (4.1)$$

The voltage value applied to the system is transferred into a DM406 A/D converter PC/104 module. The DM406 A/D converter module converts the analog voltage input into 12-bit twos complement form. Then, the result must be converted to straight binary. The conversion from twos complement form to straight binary formula is simple: for values greater than 2047, 4096 is subtracted from the value to get the sign of the voltage. Each bit of the A/D module represents 2.44 millivolts. Therefore, the signed voltage is multiplied by 0.00244 to obtain input voltage values. Finally, equation (4.1) is

calculate speed values. All these calculations are performed in the sampler object of the SANS software.

Figure 4.1 shows the estimated position against time. The system is tested with the north heading and three feet per second speed input. The figure shows that the north position is increasing by almost three feet per second, and the east position is almost zero.

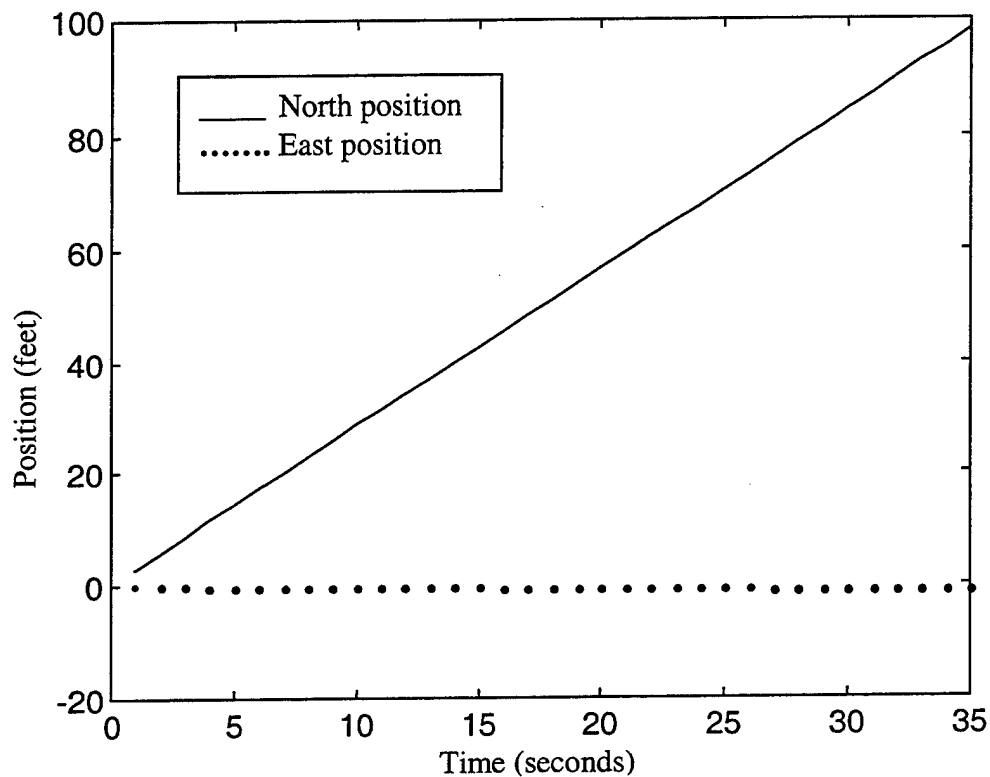


Figure 4.1 Plot of Position vs. Time with the Speed of 3 ft/sec.

Figure 4.2 shows the estimated position against time. The system is tested with the north heading and ten feet per second speed input. The figure displays that the north position is increasing by almost ten feet per second, and the east position is almost zero.

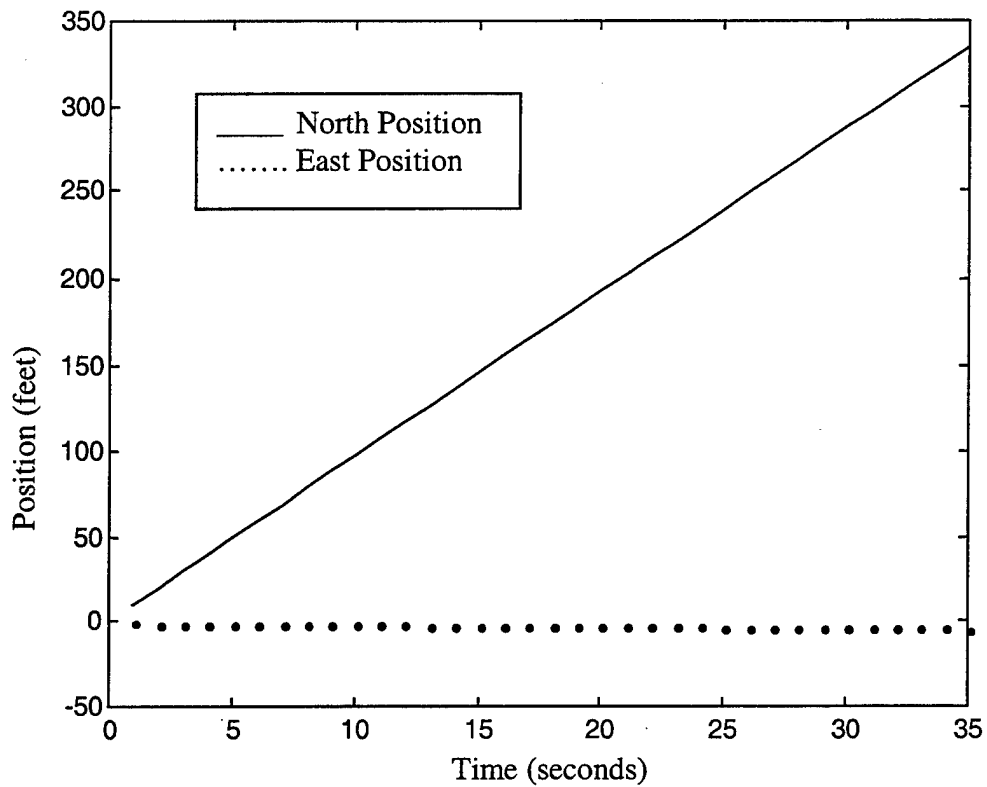


Figure 4.2 Plot of Position vs. Time with the Speed of 10 ft/sec.

Similarly, the system was tested with east heading information. Figure 4.3 shows the estimated position against time for three feet per second, and figure 4.4 shows the estimated position against time for ten feet per second. Both tests indicate that the east position increases with respect to speed information, and north position is almost zero.

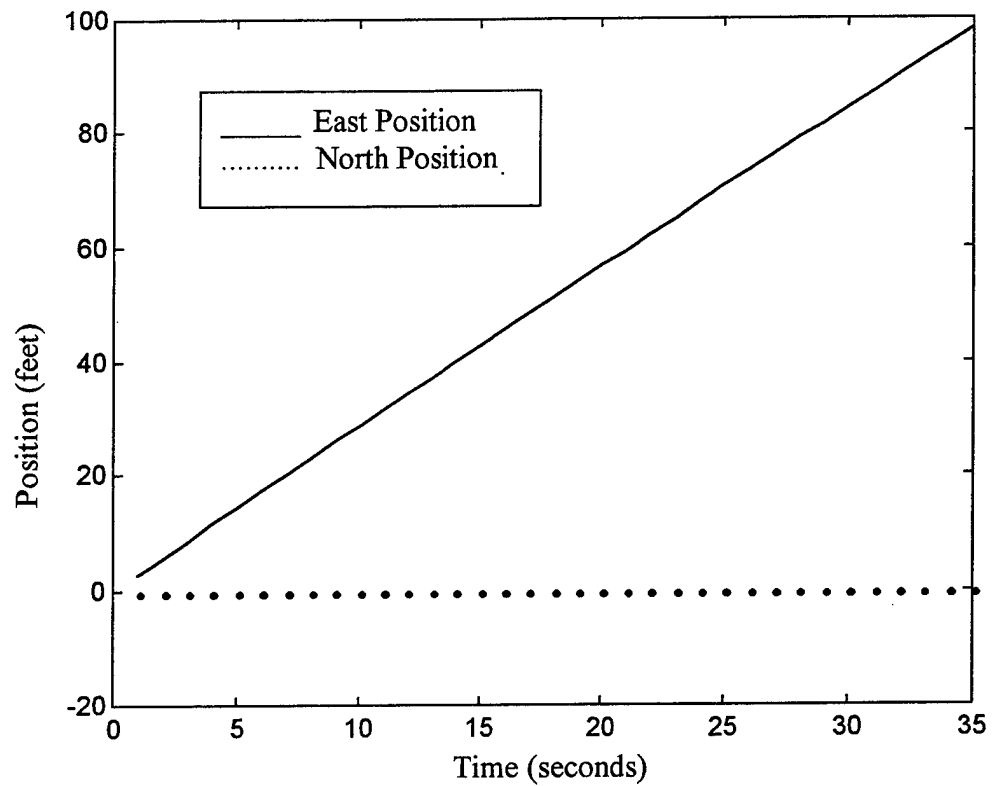


Figure 4.3 Plot of Position vs. Time with the Speed of 3 ft/sec.

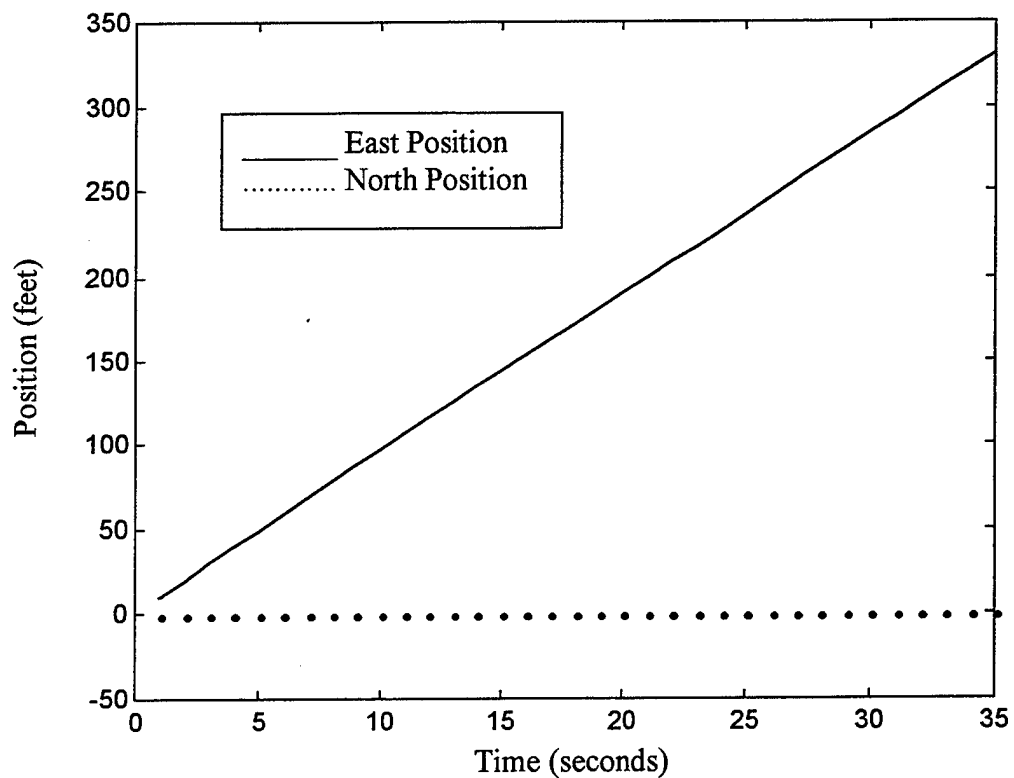


Figure 4.4 Plot of Position vs. Time with the Speed of 10 ft/sec.

C. SUMMARY

The new SANS configuration was tested on a bench with north and east heading information. The bench testing proved that the INS object properly calculates the estimated position using asynchronous Kalman filter.

V. CONCLUSIONS

A. SUMMARY

The purpose of this thesis was to develop a prototype hardware platform and software interface designed to meet the mission requirements of the SANS. The objective of designing the SANS system is to demonstrate the feasibility of using low-cost, small components to navigate inertially between DGPS fixes.

The research issues addressed by this thesis were: (1) Integrate an AMD 586DX133 based PC/104 computer into the SANS system, (2) Develop the software interface, which communicates between the GPS receiver, the compass, the IMU and, the processing computer, (3) Implement the asynchronous Kalman filter developed in reference [3] into the new hardware system, and (4) Test and evaluate the hardware and software.

The work conducted in addressing the first of these research issues resulted in a new hardware configuration of the SANS system. The new hardware configuration uses an AMD 586DX133 based PC/104 computer, a C4-104 Serial I/O Module and a Crossbow DMU-VG Six Axis IMU. The components in SANS were chosen based on cost, size, and ease of operation. The new components reduced the size of the system by 52% and increased the sampling rate to more than 80Hz. Use of the PC/104 industrial standard enhanced the reliability, flexibility, and compatibility of the SANS system.

In addressing the second research issue, some significant as well as minor changes were made in the SANS software. In the current system, the IMU data, compass data and GPS data are all received via serial port communication objects. The SANS

software was compiled under the Borland version 5.0, C++ compiler. The software runs on a DOS (standard) platform.

For the third research question, the previous SANS constant-gain filter was replaced by an asynchronous Kalman filter, which has six states for orientation estimation (still constant gain), and eight states for position estimation. The asynchronous nature of DGPS measurements due to asynchronous reacquisition time of satellite signals and asynchronous submergence and surfacing of the AUV, made the selection of an asynchronous Kalman filter algorithm a logical choice.

After integrating the new hardware and implementing the new software, bench testing was conducted and indicated that the newly designed system provides a higher level of performance than previous versions of SANS. The examination of the experimental data indicates that the new IMU used in this research is capable of meeting all SANS requirements. The new data acquisition and processing unit increased the speed, reliability, and compatibility of the system. Testing the new asynchronous Kalman filter with different speed and heading data indicates that the new navigation filter works properly.

B. FUTURE RESEARCH

Technology advances, software development, and the amount of research put into testing and evaluation show that the future of SANS is subject to many changes. The goal of choosing the new components in the SANS system should always be to reduce the size, while improving performance and decreasing cost.

Addition of the Proxim Range LAN2 PC card to the system should be considered as a future component. This card would give SANS more portability and potentially change the way the sensors are integrated and utilized for applications other than AUVs.

In order to acquire more accurate navigation information, the four year old DGPS package should be replaced with a system that is smaller and more accurate.

The asynchronous Kalman filter has been implemented as a navigation filter. More testing of the filter is needed, in order to adjust filter constants.

The new water speed sensor must be integrated into the system. The water speed sensor should also use a serial port communication object to obtain water speed information.

Tilt table tests must be performed to examine the IMU data. Compass calibration is examined in reference [6]. When SANS reaches the stage where hardware and software are fully integrated, at-sea trials will be needed to prove its operation.

APPENDIX A: REAL TIME NAVIGATION SOURCE CODE (C++)

A. TOETYPES.H

```
#ifndef __TOETYPES_H
#define __TOETYPES_H

#include "globals.h" //Types used by serial communications software
#define GPSBLOCKSIZE 76 //Size of Motorola @Ea position message
#define CRBBLOCKSIZE 22
#define PACKETSIZE 133 // Size of packet received via X-modem protocol
#define COMPSIZE 60
#define ONE_G 32.2185 // One g in feet per second per sec.
#define GRAVITY 32.2185 // In feet per second per sec.
#define TicksToSecs(x) ((double) ((10 * x) / 182))

typedef char ONEBYTE;
typedef short TWOBYTE;
typedef long FOURBYTE;
typedef unsigned char UNSIGNED_ONEBYTE;
typedef unsigned short UNSIGNED_TWOBYTE;
typedef unsigned long UNSIGNED_FOURBYTE;

// Holds lat/long expressed in miliseconds
struct latLongMilSec {
    long latitude;
    long longitude;
};

// Holds a latitude or longitude expressed in hours minutes and degrees
struct T_GEODETTIC {
    TWOBYTE degrees;
    UNSIGNED_TWOBYTE minutes;
    double seconds;
};

// Holds a latitude and longitude expressed as T_GEODETTICs
struct latLongPosition {
    T_GEODETTIC latitude;
    T_GEODETTIC longitude;
};

// Holds a grid position
struct grid {
    double x,y,z;
};

// 3 X 3 matrix
struct matrix {
    float element[3][3];
};

// 3 X 1 matrix or vector
struct vector {
    float element[3];
};
```

```

// Oversize area to hold a GPS message
typedef BYTE GPSdata[2 * GPSBLOCKSIZE];

// Oversize area to hold a Crossbow IMU message
typedef BYTE CRBdata[2 * CRBBLOCKSIZE];

// Defines a type for holding compass messages
typedef BYTE compData[2 * COMPSIZE];

//stampedSample structure
struct stampedSample {
    Boolean gpsFlag;           // True if GPS fix obtained
    Boolean insFlag;           // True if INS fix obtained
    latLongPosition navLatLong; //posit in hours,mins,secs
    grid est;                  // position as estimated by the INS
    GPSdata satPosition;       // the latest GPS position
    CRBdata crossbowData;      // the Crossbow data
    float rawSample[8];        //Original readings for post process
    double sample[11];         // sampler converted sample
    double deltaT;             // delta of the sample
    float bias[3];             // bias corrections
    float current[3];          // error correction current
    float rawVelocity[3];
};
#endif

```

B. TOEFISH.CPP

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <iostream.h>
#include <conio.h>
#include <dos.h>
#include <time.h>

#include "toetypes.h"
#include "nav.h"
#include "compport.h"
#include "crbbuff.h"
#include "crb.h"

crbBufferClass buf;
extern compassPortClass port2; // so breakhandler can call destructors
extern gpsPortClass port1;    // clean up on program exit
extern crbPortClass port3;

int breakHandler(void);
void screenSetUp(void);
void printPosition (const latLongPosition&);
void positOut(stampedSample& posit);

// Write an INS packet and its timeStamp to the outPut file
void writeData(const stampedSample& drPosition, ofstream&, float
elapsedTime);
// Write a GPS message to the outPut file.
void writeGpsData(const GPSdata& satPosition);

// Write data in list format for lisp program
void writeLispData(float deltaT, stampedSample& current,
                  ofstream& lispData);

/*****
PROGRAM:Main
AUTHOR: Eric Bachmann,Dave Gay,Rick Roberts, Kadir Akyol
DATE: 11 July 1995, last modified March 1999
FUNCTION: Drives the navigator and its associated software.
COUNTS the positions & displays each to the screen. Exited only when
control break (Ctrl c) is entered at the keyboard.
RETURNS: 0
CALLED BY: none
CALLS:initializeNavigator (nav.h)
       navPosit (nav.h)
       printPosition
       breakHandler
*****/

int
main ()
{
    crbPortClass read;
    ctrlbrk(breakHandler); // trap all breaks to release com ports
    setcbrk(1);           // turn break checking on at all times
```

```

char dataFile[] = "att.dat";
char lispFile[] = "lisp.dat";

cout << "\nWriting attitude data to " << dataFile << endl;

// Instantiate the navigator
navigatorClass *navPtr = new navigatorClass;
navigatorClass &nav1 = *navPtr;

ofstream attitudeData(dataFile);
ofstream lispData(lispFile);

stampedSample curLoc; // Lat/Long of most recent fix

curLoc.navLatLong.latitude.degrees = 0.0;
curLoc.navLatLong.latitude.minutes = 0.0;
curLoc.navLatLong.latitude.seconds = 0.0;
curLoc.navLatLong.longitude.degrees = 0.0;
curLoc.navLatLong.longitude.minutes = 0.0;
curLoc.navLatLong.longitude.seconds = 0.0;

read.Send('R'); // reset command to IMU
cerr << "Reset is sent to IMU " << endl;

read.Send('a'); // VG mode command to IMU
cerr << "VG mode is selected " << endl;

read.Send(0x7A); // 'z' command to calibrate and set
cerr << "zeroing..." << endl; // for rate sensor

read.Send(0xFF); // 2nd byte of 'z' command
cerr << "zeroing..." << endl;
delay(10);

read.Send(0x54); // 'T' command for time constant
cerr << "time constant setting..." << endl;

read.Send(0xFF); // 2nd byte of 'T' command
cerr << "time constant setting..." << endl;
delay(10);

read.Send('C'); // Continuous transmission mode
cerr << "Continuous mode " << endl;

Boolean gpsReceived(FALSE); // True if gps received
Boolean fixReceived(FALSE); // True if a new fix was received

int fixCount(0); // Count of navigation fixes
float timeCount(0.0); // Counter for screen output
float timeTotal(0.0); // Total elapsed time

cerr << "\nInitializing . . ." << endl;

nav1.initializeNavigator(curLoc);

clrscr();

```

```

gotoxy(1,6);
cerr << "Initialization Complete!" << endl;
cout << "Initial Position:" << endl;

// Print the initial position
cout << "latitude: " <<
curLoc.navLatLong.latitude.degrees << ':'
    << curLoc.navLatLong.latitude.minutes << ':'
    << curLoc.navLatLong.latitude.seconds << endl;
cout << "longitude: " << curLoc.navLatLong.longitude.degrees << ':'
    << curLoc.navLatLong.longitude.minutes << ':'
    << curLoc.navLatLong.longitude.seconds;

screenSetUp();

//Attempt to get a fix from the navigator
while (TRUE) {
    fixReceived = nav1.navPosit(curLoc);

    if (fixReceived) {          // New fix received
        // Print info to screen at designated print interval
        fixCount++;
        timeCount += curLoc.deltaT;
        timeTotal += curLoc.deltaT;

        if (curLoc.gpsFlag) {
            gpsReceived = TRUE; //Keep DGPS indicator displayed
            writeLispData(timeCount, curLoc, lispData);
        }

        if (timeCount >= 1.0) {

            if (gpsReceived == TRUE) {
                gotoxy(20,11);
                cout << "DGPS";
                gpsReceived = FALSE;
            }
            else {
                gotoxy(20,11);
                cout << "    ";
            }

            gotoxy(9,11);
            cout << fixCount << endl;

            positOut(curLoc);
            writeData(curLoc, attitudeData, timeTotal);
            writeLispData(timeCount, curLoc, lispData);
            timeCount = 0.0;

        } // end if
    } // end if
} //end while
} // end main

```

```

/*****
PROGRAM:    printPosition
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Displays position to the screen
RETURNS:     void
CALLED BY:  main
CALLS:       none
*****/

void printPosition (const latLongPosition& posit)
{
    gotoxy(11,14);
    cout << posit.latitude.degrees << ':'<<
        posit.latitude.minutes << ':' << posit.latitude.seconds <<
        endl;
    gotoxy(12,15);
    cout << posit.longitude.degrees << ':'<<
        posit.longitude.minutes << ':' << posit.longitude.seconds <<
        endl;
}

/*****
PROGRAM:    breakHandler
AUTHOR:Eric Bachmann,Dave Gay, Rick Roberts, Kadir Akyol
DATE:       11 July 1995 last modified March 1999
FUNCTION:    Cleans up com ports upon program exit.
RETURNS:     0
CALLED BY:  main
CALLS:       compass port and gps port destructors
*****/

int breakHandler(void)
{
    crbPortClass re;
    re.Send('R');          // Send reset command to IMU
    delay(100);
    buf.~crbBufferClass(); // clears the crossbow buffer
    port3.~crbPortClass();
    port2.~compassPortClass();
    port1.~gpsPortClass();
    return 0;              // keep the compiler happy
}

/*****
PROGRAM:    screenSetup
AUTHOR:     Eric Bachmann, Randy Walker
DATE:       12 May 1996
FUNCTION:    Sets up the output screen
RETURNS:     0
CALLED BY:  main
CALLS:       none
*****/

void screenSetUp(void)
{
    gotoxy(4,11);

```

```

cout << "Fix ";

gotoxy(1,14);
cout << "Latitude: " << "\nLongitude: ";

gotoxy(1,17);
cout << "Roll: " << "\nPitch: ";

gotoxy(1,25);
cout << "deltaT: ";

int col(45),row(1);

gotoxy(col,row++);
cout << "x accel: ";
gotoxy(col,row++);
cout << "y accel: ";
gotoxy(col,row++);
cout << "z accel: ";
gotoxy(col,row++);
cout << "phi dot: ";
gotoxy(col,row++);
cout << "theta dot: ";
gotoxy(col,row++);
cout << "psi dot: ";
gotoxy(col,row++);
cout << "water speed: ";
gotoxy(col,row++);
cout << "heading: ";

col = 45;
row = 12;

gotoxy(col,row++);
cout << "x: ";
gotoxy(col,row++);
cout << "y: ";
gotoxy(col,row++);
cout << "z: ";
gotoxy(col,row++);
cout << "phi: ";
gotoxy(col,row++);
cout << "theta: ";
gotoxy(col,row++);
cout << "psi: ";

gotoxy(45,20);
cout << "Bias Values";

gotoxy(60,20);
cout << "Current Values";
}

```

```

/*****
PROGRAM:    positOut
AUTHOR:     Eric Bachmann
DATE:       21 October 1996
FUNCTION:    Updates the Screen
RETURNS:    0
CALLED BY:  main
CALLS:      none
*****/

void positOut(stampedSample& posit)
{
    printPosition(posit.navLatLong);
    int j;

    // Output the bias values
    for(j = 3; j < 6; j++) {
        gotoxy(45,j+18);
        cout << posit.bias[j];
    }

    //Display linear accelrations,angular rates,water speed and comp hdg
    for (j = 0; j < 8; j++) {
        gotoxy(59,j+1);
        cout << posit.rawSample[j];
    }

    // Display time delta to the screen.
    gotoxy(9,25);
    cout << posit.deltaT;

    // Display roll and pitch
    gotoxy(8,17);
    cout << (posit.sample[3] * radToDeg);
    gotoxy(8,18);
    cout << (posit.sample[4] * radToDeg);
    // Display current location and posture
    for (j = 0; j < 6; j++) {
        gotoxy(52,j+12);
        cout << posit.sample[j];
    }
    // Display error current values
    for (j = 0; j < 3; j++) {
        gotoxy(60,j+21);
        cout << posit.current[j];
    }

    // Output the biases
    for (j = 0; j < 3; j++) {
        gotoxy(45,j+21);
        cout << posit.bias[j];
    }
}

```

```

/*****
PROGRAM:   writeData
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Writes the packet and the time stamp contained in a
            stamped sample to the out put file for post processing.
RETURNS:    void
CALLED BY:  navPosit (nav.cpp)
CALLS:      None
*****/

```

```

void writeData(const stampedSample& drPosition,
               ofstream& attitudeData,float elapsedTime)

```

```

{
    // Output attitude data to a file
    attitudeData
        << elapsedTime << ' '
        << drPosition.sample[0] << ' '
        << drPosition.sample[1] << ' '
        << drPosition.sample[2] << ' '
        << (radToDeg * drPosition.sample[3]) << ' '
        << (radToDeg * drPosition.sample[4]) << ' '
        << (radToDeg * drPosition.sample[5]) << ' '
        << drPosition.sample[6] << ' '
        << (radToDeg * drPosition.sample[7]) << ' '
        << drPosition.current[0] << ' '
        << drPosition.current[1] << endl;
}

```

```

/*****
PROGRAM:   writeData
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Writes the packet and the time stamp contained in a
            stamped sample to the out put file for post processing.
RETURNS:    void
CALLED BY:  navPosit (nav.cpp)
CALLS:      None
*****/

```

```

void writeLispData(float deltaT,stampedSample& current,
                  ofstream& lispData)

```

```

{
    // Output attitude data to a file
    if (current.gpsFlag) {
        lispData
            << '(' << deltaT << ' '
            << current.rawVelocity[0] << ' '
            << current.rawVelocity[1] << ' '
            << current.est.x << ' '
            << current.est.y << ')' << endl;
    }
    else {
        lispData
            << '(' << current.deltaT << ' '
            << current.rawVelocity[0] << ' '
            << current.rawVelocity[1]

```

```
        << " nil nil)"<< ' ' << endl;
    }
}
// end of file toefish.cpp
```

C. NAV.H

```
#ifndef _NAVIGATOR_H
#define _NAVIGATOR_H
#include <stdio.h>
#include <fstream.h>
#include <iostream.h>
#include <math.h>
#include <dos.h>

#include "toetypes.h"
#include "globals.h"
#include "gps.h"
#include "ins.h"

/*****
CLASS:      navigatorClass
AUTHOR:     Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995, Modified January 1997
FUNCTION:    Combines GPS and INS information to return the current
              estimated position.
*****/
class navigatorClass {

public:

    // Constructor, initializes object slots
    navigatorClass() : gpsSpeedSum(0.0), insSpeedSum(0.0)
    { cerr << "\nconstructing nav1" << endl; };

    ~navigatorClass() {} // Destructor

    // provides the navigator's best estimate of current position
    Boolean navPosit (stampedSample&);

    // Initialize the navigator
    Boolean initializeNavigator(stampedSample&);

    void userInitNav(stampedSample&); //Allows user to initialize nav

private:

    double gpsSpeed, insSpeed, gpsSpeedSum, insSpeedSum;

    insClass ins1; // ins object instance
    gpsClass gps1; // gps object instance

    // Obtains system time to utilize for origin
    double getSystemTime();

    latLongMilSec origin; //lat-long of navigational origin

    // Returns the position in Miliseconds
    latLongMilSec getMilSec(const GPSdata&);

    // Returns the position in degrees, minutes, seconds and milisecs
```

```

        latLongMilSec latLongToMilSec(const latLongPosition&);
        // Convert position in milSec to degrees, minutes, seconds and
milsec    latLongPosition milSecToLatLong(const latLongMilSec&);

        // Convert xy (grid) position to lat long
        latLongMilSec gridToMilSec(const grid&);

        // Converts lat/long to xy position
        grid milSecToGrid(const latLongMilSec&);

        // Parses and returns the time of a GPS message.
        double getGpsTime(const GPSdata& rawMessage);

        // Parses and returns the velocity of a GPS message.
        double getGpsVelocity(const GPSdata& rawMessage);
};
#endif

```

D. NAV.CPP

```
#include <signal.h>
#include <dos.h>
#include <time.h>
#include <stdlib.h>
#include "nav.h"

#define SIGFPE 8          // Floating point exception

/*****
PROGRAM:  navPosit
AUTHOR:   Eric Bachmann, Dave Gay, Kadir Akyol
DATE:    11 July 1995 last modified March 1999
FUNCTION: Provides the navigator's best estimate of current
position. Attempts to obtain GPS and INS position fixes from the gps
and ins objects and copies the most accurate fix available into the
input argument 'navPosition'. Sets a return flag to indicate
whether a valid fix was obtained.
RETURNS:  TRUE, a valid position fix is in the variable
'navPosition'. FALSE, otherwise.
CALLED BY: towfish.cpp (main)
CALLS:    gpsPosition (gps.h)          gridToMilSec (nav.h)
          correctPosition (ins.h)      milSecToGrid (nav.h)
          insPosition (ins.h)          milSecToLatLong (nav.h)
          getMilSec (nav.h)            writeScriptPosit (nav.h)
*****/

void fpeNavPosit(int sig)
{if (sig == SIGFPE) cerr << "floating point error in navPosit\n";}

Boolean navigatorClass::navPosit (stampedSample& posit)
{
    signal (SIGFPE, fpeNavPosit);

    latLongMilSec gpsMilSec; //latest GPS position in milsec
    latLongMilSec insMilSec; //latest INS position in milsec

    // Attempt to get the INS and GPS positions
    posit.gpsFlag = gps1.gpsPosition(posit.satPosition);

    if (posit.gpsFlag) {          // GPS positions obtained?
        // Parse position from GPS message
        gpsMilSec = getMilSec(posit.satPosition);

        posit.est = milSecToGrid(gpsMilSec);

        // Convert position in milisec to latitude and longitude.
        posit.navLatLong = milSecToLatLong(gpsMilSec);
    }
    posit.insFlag = ins1.insPosition(posit);

    if (posit.insFlag) {          // Only INS position obtained?

        insMilSec = gridToMilSec(posit.est);
    }
}
```

```

        posit.navLatLong = milSecToLatLong(insMilSec);

        insSpeed = posit.sample[6];

        return TRUE;
    }
    else {
        return FALSE;
    }
}

/*****
PROGRAM:    initializeNavigator
AUTHOR:    Eric Bachmann, Dave Gay, Rick Roberts
DATE:      11 July 1995
FUNCTION:   Obtains an initial GPS fix for use as a navigational
            origin for grid positions used by the INS object. Saves the origin
            and passes it to the INS object in latLong form.
RETURNS:    TRUE
CALLED BY:  towfish (main)
CALLS:      gpsPosition (gps.cpp)      writeGpsData(nav.cpp)
            correctPosition (ins.cpp)  getMilSec (nav.cpp)
            writeInsData(nav.cpp)      milSecToGrid (nav.cpp)
*****/

Boolean navigatorClass::initializeNavigator(stampedSample& posit)
{
    Boolean gpsFlag(FALSE);

    cerr << "Initializing Navigator." << endl;
    cerr << "    Initializing GPS." << endl;

    // Loop until an initial GPS fix is obtained.
    for(int i = 1 ; ((i < 100) &&(gpsFlag == FALSE)); i++) {
        if (gps1.gpsPosition(posit.satPosition)) {
            gpsFlag = TRUE;
        }
        else {
            delay(100);
        }
    }

    if (gpsFlag == FALSE) {
        cerr << "\nWARNING: UNABLE TO OBTAIN INITIAL GPS FIX!" << endl;
        userInitNav(posit);
    }

    cerr << "    GPS initialization complete." << endl;

    // Convert position in milisec to latitude and longitude.
    posit.navLatLong = milSecToLatLong(getMilSec(posit.satPosition));

    // Save navigational origin for later grid position conversions.
    origin = getMilSec(posit.satPosition);
}

```

```

    // Pass time of first GPS fix to INS object initialization routine.
    ins1.insSetUp(getGpsTime(posit.satPosition), posit);
    cerr << "Navigator initialization complete." << endl;

    return TRUE;
}

/*****
PROGRAM:    userInitNav
AUTHOR:     Rick Roberts
DATE:       03 November 1996
FUNCTION:    Allows user to input current position and initialize nav
             if no gps fix is available.(ie for testing)
RETURNS:     void
CALLED BY:   initializeNavigator
CALLS:       getMilSec (nav.cpp), getSystemTime (nav.cpp)
*****/

void navigatorClass::userInitNav(stampedSample& posit)
{
    int choice;

    cerr << "\nEnter a 0 to enter posit and continue without GPS"
         << "\nEnter a 1 to continue without GPS or initial posit, or"
         << "\nEnter a 2 to exit: "
         << endl;
    cin >> choice;

    if (choice == 0) {
        cerr << "\nEnter current position in the following format: "
             << endl;
        cerr << "Latitude: (36, Enter, 35 Enter, 41.5 Enter)" << endl;
        cin >> posit.navLatLong.latitude.degrees;
        cin >> posit.navLatLong.latitude.minutes;
        cin >> posit.navLatLong.latitude.seconds;

        cerr << "Longitude: (-121, Enter, 52, Enter, 30.2, Enter)"
             << endl;
        cin >> posit.navLatLong.longitude.degrees;
        cin >> posit.navLatLong.longitude.minutes;
        cin >> posit.navLatLong.longitude.seconds;
    }
    else if (choice == 2) {
        exit(1);
    }

    // Save nav origin for later grid position conversions
    origin = latLongToMilSec(posit.navLatLong);
}

```

```

/*****
PROGRAM:    latLongToMilSec
AUTHOR:     Rick Roberts
DATE:       22 January 1997
FUNCTION:    Converts a position expressed in latitude and longitude
degrees, minutes and seconds to mili seconds & returns it.
RETURNS:    latLongMilSec
CALLED BY:  userInitNav
CALLS:      none
*****/

latLongMilSec navigatorClass::latLongToMilSec(const latLongPosition&
latLong)
{
    latLongMilSec milSec;
    milSec.latitude = (latLong.latitude.degrees *
        DEGREES_TO_MSECS)+(latLong.latitude.minutes *
        MINS_TO_MSECS)+(latLong.latitude.seconds * 1000.0);

    milSec.longitude = (latLong.longitude.degrees *
        DEGREES_TO_MSECS)+(latLong.longitude.minutes *
        MINS_TO_MSECS)+(latLong.longitude.seconds * 1000.0);

    return milSec;
}

/*****
PROGRAM:    getSystemTime
AUTHOR:     Rick Roberts
DATE:       03 November 1996
FUNCTION:    Obtains system time to utilize for origin.
RETURNS:    double (origin time in seconds)
CALLED BY:  userInitNav
CALLS:      dos time function
*****/

double navigatorClass::getSystemTime()
{
    dostime_t* sysTime;    // pointer to dos time structure

    _dos_gettime(sysTime);

    return double((sysTime->hour * 3600.0) + (sysTime->minute * 60.0)+
        (sysTime->second));
}

/*****
PROGRAM:    getMilSec
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Extracts a position in miliseconds from a Motorola
(@@Ba)position contained in the input argument 'rawMessage'.
RETURNS:    The latitude and longitude in miliseconds.
CALLED BY:  navPosit (nav.cpp)
            initializeNavigator (nav.cpp)
CALLS:      none.
*****/

```

```

latLongMilSec navigatorClass::getMilSec(const GPSdata& rawMessage)
{
    FOURBYTE temps4byte;
    latLongMilSec position;

    temps4byte      = rawMessage[15];
    temps4byte      = (temps4byte<<8) + rawMessage[16];
    temps4byte      = (temps4byte<<8) + rawMessage[17];
    temps4byte      = (temps4byte<<8) + rawMessage[18];

    position.latitude = temps4byte;

    temps4byte      = rawMessage[19];
    temps4byte      = (temps4byte<<8) + rawMessage[20];
    temps4byte      = (temps4byte<<8) + rawMessage[21];
    temps4byte      = (temps4byte<<8) + rawMessage[22];

    position.longitude = temps4byte;

    return position;
}

/*****
PROGRAM:    milSecToLatLong
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Converts a position expressed totally in milliseconds to
degrees, minutes, seconds and milliseconds.
RETURNS:   The position in degrees, minutes, seconds and
milliseconds.
CALLED BY: navPosit (nav.cpp)
CALLS:     none
*****/

latLongPosition navigatorClass::milSecToLatLong(const latLongMilSec&
milSec)
{
    latLongPosition position;

    double degrees, minutes;

    degrees = (double)milSec.latitude * MSECS_TO_DEGREES;
    position.latitude.degrees = (TWOBYTE)degrees;

    if(degrees < 0) {
        degrees = fabs(degrees);
    }
    minutes = (degrees - (TWOBYTE)degrees) * 60.0;
    position.latitude.minutes = (TWOBYTE)minutes;
    position.latitude.seconds = (minutes - (TWOBYTE)minutes) * 60.0;

    degrees = (double)milSec.longitude * MSECS_TO_DEGREES;
    position.longitude.degrees = (TWOBYTE)degrees;

```

```

        if(degrees < 0) {
            degrees = fabs(degrees);
        }
        minutes = (degrees - (TWOBYTE)degrees) * 60.0;
        position.longitude.minutes = (TWOBYTE)minutes;
        position.longitude.seconds = (minutes - (TWOBYTE)minutes) * 60.0;

        return position;
    }

/*****
PROGRAM:    gridToMilSec
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Convert a grid position to a latitude and longitude in
             mili-seconds and returns the result.
RETURNS:     The latitude and longitude in miliseconds.
CALLED BY:   navPosit (nav.cpp)
CALLS:       none
*****/

void fpeGridToMilSec(int sig)
{if (sig == SIGFPE) cerr << "floating point error in gridToMilSec\n";}

latLongMilSec navigatorClass::gridToMilSec(const grid& posit)
{
    signal(SIGFPE, fpeGridToMilSec);
    latLongMilSec latLong;

    // converts grid in ft to latitude
    latLong.latitude = origin.latitude + posit.x / LatToFt;
    // converts grid in ft to longitude
    latLong.longitude = origin.longitud + HemisphereConversion *
    (posit.y / LongToFt);

    return latLong;
}

/*****
PROGRAM:    milSecToGrid
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Convert a latitude and longitude expressed in miliseconds
             to a grid position in xy coordinates in feet from the origin.
RETURNS:     The grid position
CALLED BY:   navPosit(nav.cpp), initializeNavigator(nav.cpp)
CALLS:       none
COMMENTS:    altitude is always assumed to be zero.
*****/

grid navigatorClass::milSecToGrid(const latLongMilSec& posit)
{
    grid position;

    position.x = (posit.latitude - origin.latitude) * LatToFt;
    position.y = (posit.longitude - origin.longitude) * LongToFt;
}

```

```

    position.z = 0;

    return position;
}

/*****
PROGRAM:      getGpsTime
AUTHOR:      Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Parse the time of a gps message.
RETURNS:     The time of the gps message in seconds
CALLED BY:   navPosit (nav.cpp), initializeNavigator(nav.cpp)
CALLS:       none
*****/

double navigatorClass::getGpsTime(const GPSdata& rawMessage)
{
    UNSIGNED_ONEBYTE    tempchar, hours, minutes;
    UNSIGNED_FOURBYTE    tempu4byte;
    double seconds;

    hours    = rawMessage[8];
    minutes  = rawMessage[9];

    tempchar    = rawMessage[10];
    tempu4byte   = rawMessage[11];
    tempu4byte   = (tempu4byte<<8) + rawMessage[12];
    tempu4byte   = (tempu4byte<<8) + rawMessage[13];
    tempu4byte   = (tempu4byte<<8) + rawMessage[14];
    seconds = (double)tempchar + (((double)tempu4byte)/1.0E+9);

    return hours * 3600.0 + minutes * 60.0 + seconds;
}

/*****
PROGRAM:      getGpsVelocity
AUTHOR:      Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Parse the velocity out of a gps message.
RETURNS:     The velocity of the gps message in feet per second
CALLED BY:   navPosit (nav.cpp), initializeNavigator (nav.cpp)
CALLS:       none
*****/

double navigatorClass::getGpsVelocity(const GPSdata& rawMessage)
{
    UNSIGNED_ONEBYTE tempchar=rawMessage[31];

    return (double)(3.2804 * ((tempchar << 8) + rawMessage[32]) /
100.00);
}
// end of file nav.cpp

```

E. GPS.H

```
#ifndef _GPS_H
#define _GPS_H

#include <iostream.h>
#include <fstream.h>
#include <conio.h>
#include "toetypes.h"
#include "globals.h"
#include "gpsPort.h"

/*****
CLASS:      gpsClass
AUTHOR:     Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995, last modified January 1997
FUNCTION:    Reads GPS messages from the GPS buffer. Checks for valid
checksum and minimum number of satellites in view.
*****/

class gpsClass {

public:

    // Class constructor and destructor
    gpsClass() { cerr << "\nconstructing gps1" << endl; };
    ~gpsClass() {}

    // returns the latest gps position and a flag
    Boolean gpsPosition(GPSdata&);

private:

    // calculates the check sum of the message
    Boolean checksumCheck(const GPSdata);

};

#endif
```

F. GPS.CPP

```
#include <math.h>
#include "gps.h"

//instantiates serial port communications on comm1,global
//to allow interrupt processing
gpsPortClass port1;

/*****
NAME:      gpsPosition
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Determines if an updated gps position message is
available and copies it into the input argument 'rawMessage'. If the
message has a valid checksum and was obtained with atleast three
satelites in view, a 'TRUE' is returned to the caller,
indicating that the message is valid.
RETURNS:    TRUE, if a valid position message is contained in the
input argument.
CALLED BY:  navPosit (navigator.h)
CALLS:      Get (buffer.h)      checksumCheck (gps.h)
*****/

Boolean gpsClass::gpsPosition(GPSdata& rawMessage)
{
    Boolean validFlag(TRUE);
    unsigned long Mask(4);
    if (port1.Get(rawMessage)) {

        // Check for a valid check sum and 3 or more satelites and DGPS
        if (!checksumCheck(rawMessage)) {
            cerr << "bad checksum" << endl;
            validFlag = FALSE;
        }
        if (!(rawMessage[39] >= 2)) {
            cerr << "Too few satelites" << endl;
            validFlag = FALSE;
        }

        if (!((rawMessage[GPSBLOCKSIZE - 4]&Mask) == Mask)) {
            cerr << "No DGPS" << endl;
            validFlag = FALSE;
        }

        return validFlag;
    }
    else {
        return FALSE;    // No updated position is available.
    }
}
```

```

/*****
PROGRAM:   checksumCheck
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Takes an exclusive or of bytes 2 through 78 in a Motorola
            format(@@EA) position message and compares it to the checksum of the
            message.
RETURNS:    TRUE, if the message contains a valid checksum
CALLED BY:  gpsPosition (gps)
CALLS:      none
*****/

Boolean gpsClass::checksumCheck(const GPSdata newMessage)
{
    BYTE chkSum(0);

    for (int i = 2; i < GPSBLOCKSIZE - 3; i++) {
        chkSum ^= newMessage[i];
    }

    return Boolean(chkSum == newMessage[GPSBLOCKSIZE - 3]);
}
// end of file gps.cpp

```

G. INS.H

```
#ifndef _INS_H
#define _INS_H
#include <time.h>
#include <math.h>
#include <dos.h>
#include <stdio.h>
#include <conio.h>
#include <fstream.h>
#include <iostream.h>
#include <assert.h>

#include "toetypes.h"
#include "globals.h"
#include "sampler.h"
#include "Matrix.h"

/*****
CLASS:      insClass
AUTHOR:     Eric Bachmann, Dave Gay, Kadir Akyol
DATE:       11 July 1995 last modified March 1999
FUNCTION:    Takes in linear accelerations, angular rates, speed and
             heading information and uses Kalman filtering techniques to return a
             dead reconing position.
*****/

class insClass {

public:

    insClass();          // Constructor, initializes gains
    ~insClass() {}       // destructor

    Boolean insPosition(stampedSample&); // returns ins estimated
position

    // Updates the x, y and z of the vehicle posture
    void correctPosition(stampedSample&, double);

    // Sets posture to the origin and develops initial biases
    void insSetUp(double, stampedSample&);

private:

    Matrix h, h_transpose, p, p_minus, r1, k1, k, x_hatMinus,
           x_hat, z, i, phi, phi_transpose, q, h1, h1_transpose, k2,
           r2, k3, z3, zMat;

    float posture[6]; // ins estimated posture (x y z phi theta psi)

    double velocities[6]; // ins estimated linear and angular
velocities
    float lastGPStime; // time of last gps position fix

    int tau; // filter time constant
```

```

    samplerClass sam1;    // sampler instance

    matrix rotationMatrix; // body to euler transformation matrix

    float current[3];      // ins estimated error current
    double biasCorrection[3]; // Software bias corrections for IMU
rate sensors

    // Kalman filter gains.
    float Kone1, Kone2, Ktwo, Kthree1, Kthree2, Kfour1, Kfour2, speed;

    // Transforms body coords to earth coords, removes gravity comp.
    void transformAccels (double[]);

    // Transforms water speed reading to x and y components
    void transformWaterSpeed (double, double[]);

    // Tranforms body euler rates to earth euler rates.
    void transformBodyRates (double[]);

    // Euler integrates the accelerations and updates the velocities
    void updateVelocities (stampedSample&);

    // Euler integrates the velocities and updates the posture
    void updatePosture (stampedSample&);

    // Builds the body to euler rate matrix
    matrix buildBodyRateMatrix();

    // Builds the body to earth rotation matrix
    void buildRotationMatrix();

    // Calculates the imu bias correction during set up
    void calculateBiasCorrections(stampedSample&);

    // Applies bias corrections to a sample
    void applyBiasCorrections(stampedSample&);

    // Reads filter constants from 'ins.cfg'
    void readInsConfigFile();

    //constructs h(4*8) matrix
    void constructHmatrix();

    //constructs P_minus(8*8) matrix
    void constructPminusMatrix();

    //constructs r(4*4) matrix
    void constructRlmatrix();

    //constructs h(2*8) matrix (h matrix without GPS)
    void constructHlmatrix();

    //constructs r(2*2) matrix (r matrix without GPS)
    void constructR2matrix();

    //constructs phi(8*8) matrix

```

```
void constructPhiMatrix(stampedSample&);

//constructs q(8*8) matrix
void constructqMatrix(stampedSample&);
};
// Post multiply a matrix times a vector and return result.
vector operator* (matrix&, double[]);

#endif
```

H. INS.CPP

```
#include <iostream.h>
#include <signal.h>
#include <assert.h>
#include <math.h>

#include "ins.h"

#define SIGFPE 8          // Floating point exception

/*****
PROGRAM:  insClass (constructor)
AUTHOR:   Eric Bachmann,Dave Gay,Rick Roberts, Kadir Akyol
DATE:     11 July 1995 last modified March 1999
FUNCTION: Constructor initializes kalman filter gains and linear
          and angular velocities
RETURNS:  nothing
CALLED BY: navigator class
CALLS:    none
*****/

insClass::insClass():h("h matrix",4,8),h_transpose("h transpose", 8,4),
    p_minus("p minus",8,8),r1("r1 matrix",4,4), k1("k1", 4, 4),
    k("k matrix", 8, 4), x_hatMinus("x_hatmin", 8, 1),
    x_hat("x hat", 8,1), i("unit mat", 8, 8),
    phi_transpose("phitranspose", 8, 8), h1("h1",2,8),
    h1_transpose("h1 transpose", 8, 2), r2("r2 matrix",2,2),
    k2("k2", 2, 2), k3("k mat no gps", 8, 2),
    phi("phi matrix", 8, 8), q("q matrix", 8, 8),
    p("p matrix", 8, 8),z3("z3 matrix",2,1), zMat("zMat",4,1)
{
    cerr << "\nconstructing ins1" << endl;

    readInsConfigFile();          // Read the config file

    constructHmatrix();           //constructs 4*8 h matrix

    constructPminusMatrix();      //constructs 8*8 P_minus matrix

    constructR1matrix();          //constructs 4*4 R1 matrix

    constructH1matrix();          //constructs 2*8 h matrix

    constructR2matrix();          //constructs 2*2 R2 matrix

    velocities[0] = 0.0;          // x dot
    velocities[1] = 0.0;          // y dot
    velocities[2] = 0.0;          // z dot
    velocities[3] = 0.0;          // phi dot
    velocities[4] = 0.0;          // theta dot
    velocities[5] = 0.0;          // psi dot

    posture[0] = 0.0;             // x
    posture[1] = 0.0;             // y
    posture[2] = 0.0;             // z
    posture[3] = 0.0;             // phi
}
```

```

posture[4] = 0.0;    // theta
posture[5] = 0.0;    // psi

cerr << "\nins construction complete" << endl;
}

/*****
PROGRAM: insPosit
AUTHOR:  Eric Bachmann, Dave Gay, Kadir Akyol
DATE:    11 July 1995 last modified March 1999
FUNCTION: Make dead reckoning position estimation using kalman
filtering. Inputs are linear accelerations, angular rates, speed and
heading. Primary input data is obtained from a sampler object via the
getSample method. This data is stored in the sample field of a
stampedSample structure called newSample. The sample field is then
used as a working variable as the linear accelerations and angular
rates it contains are converted to earth coordinates and integrated
to determine current velocities and posture. The data is
asynchronous kalman filtered against itself, speed and magnetic
heading.
RETURNS:      position in grid coordinates as estimated by the INS
CALLED BY:    navPosit (nav.cpp)
CALLS:        getSample (sampler.cpp)
               findDeltaT (ins.cpp)
               transformBodyRates (ins.cpp)
               buildRotationMatrix (ins.cpp)
               transformAccels (ins)
               transformWaterSpeed (ins)
*****/

void fpeInsPosit(int sig)
{if (sig == SIGFPE) cerr << "floating point error in insPosit\n";}

Boolean insClass::insPosition(stampedSample& newSample)
{
    signal(SIGFPE, fpeInsPosit);
    // Working variables
    double thetaA, phiA, xIncline, yIncline;
    // Filter correction for drift and water speed
    double waterSpeedCorrection[3];
    if (sam1.getSample(newSample)) {

        applyBiasCorrections(newSample);

        newSample.rawSample[0] = newSample.sample[0];
        newSample.rawSample[1] = newSample.sample[1];
        newSample.rawSample[2] = newSample.sample[2];
        newSample.rawSample[3] = newSample.sample[3];
        newSample.rawSample[4] = newSample.sample[4];
        newSample.rawSample[5] = newSample.sample[5];
        newSample.rawSample[6] = newSample.sample[6];
        newSample.rawSample[7] = newSample.sample[7];

        xIncline = newSample.sample[0] / GRAVITY;
        yIncline = (newSample.sample[1] -
                    (newSample.sample[5] * newSample.sample[6]))
                    / (GRAVITY * cos(posture[4]));
    }
}

```

```

if (fabs(yIncline) > 1.0) {
    static int inclineCount(0);
    gotoxy(1,24);
    cerr << "Inclination errors: " << ++inclineCount << endl;
    return FALSE;
}

// Calculate low freq pitch and roll
thetaA = asin(xIncline);
phiA = -asin(yIncline);

// Transform body rates to euler rates.
transformBodyRates(newSample.sample);

// Calculate estimated roll rate (phi-dot).
velocities[3] = newSample.sample[3] + Kone1 * (phiA - posture[3]);
// Calculate estimated pitch rate (theta-dot).
velocities[4] = newSample.sample[4] + Kone2 * (thetaA - posture[4]);
// Calculate estimated heading rate (psi-dot).
velocities[5] =
newSample.sample[5] + Ktwo * (newSample.sample[7] - posture[5]);

// integrate estimated angular rates to obtain angles
// pitch rate to angle
posture[3] += newSample.deltaT * velocities[3];
// roll rate to angle
posture[4] += newSample.deltaT * velocities[4];
// yaw rate to angle
posture[5] += newSample.deltaT * velocities[5];
if (newSample.gpsFlag) {

    zMat.copy(0,0,(newSample.sample[6] * cos (posture[5])));
    zMat.copy(1,0,(newSample.sample[6] * sin (posture[5])));
    zMat.copy(2,0,newSample.est.x);
    zMat.copy(3,0,newSample.est.y);

    h.transpose(h_transpose); //transpose of matrix h
    k1 = (((h*p_minus)*h_transpose)+r1);

    //take inverse of matrix k1
    k1 = k1.invert();

    //calculate matrix k
    k = ((p_minus * h_transpose)* k1);

    //calculate x_hat
    x_hat = ( x_hatMinus + (k * (zMat - (h * x_hatMinus))));

    //calculate I matrix
    i = i.unitMatrix (8);

    p = ((i - (k * h)) * p_minus); //calculate P matrix
}
else {
    z3.copy(0,0, (newSample.sample[6] * cos (posture[5])));
    z3.copy(1,0, (newSample.sample[6] * sin (posture[5])));

```

```

        //h1 is the h matrix without GPS
        h1.transpose(h1_transpose);

        k2 = (((h1*p_minus)*h1_transpose)+r2);

        k2 = k2.invert();

        //k matrix without gps
        k3 = ((p_minus * h1_transpose)* k2);
        x_hat = ( x_hatMinus + (k3 * (z3 - (h1 * x_hatMinus))));

        i = i.unitMatrix (8); //calculate I matrix

        p = ((i - (k3 * h1)) * p_minus); //calculate P matrix
    }

    //constructs phi matrix (8*8)
    constructPhiMatrix(newSample);

    //constructs Q matrix (8*8)
    constructQMatrix(newSample);

    //calculate x_hatMinus
    x_hatMinus = ( phi * x_hat );

    //calculate phi_transpose
    phi.transpose(phi_transpose);

    //calculate P_minus
    p_minus = ((( phi * p ) * phi_transpose ) + q );

    posture[0] += x_hat.getElement(6,0);
    posture[1] += x_hat.getElement(7,0);

    newSample.sample[0] = posture[0] ;
    newSample.sample[1] = posture[1] ;
    newSample.sample[2] = posture[2] ;
    newSample.sample[3] = posture[3];
    newSample.sample[4] = posture[4];
    newSample.sample[5] = posture[5];

    newSample.est.x = posture[0];
    newSample.est.y = posture[1];
    newSample.est.z = 0.0 ;

    return TRUE;
}
else {
    return FALSE; // New IMU information was unavailable.
}
}

```

```

/*****
PROGRAM:      insSetUp
AUTHOR:       Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Initializes the INS system. Sets the posture to the
              origin. Initializes the heading using magnetic compass information.
              Initializes the last GPS fix and last IMU information times.
RETURNS:      void
CALLED BY:    initializeNavigator (nav)
CALLS:        calculateBiasCorrections (ins)
              getSample (sampler)
              buildRotationMatrix (ins)
              transformWaterSpeed (ins)
*****/

void fpeInsSetUp(int sig)
{if (sig == SIGFPE) cerr << "floating point error in inSetUp\n";}

void insClass::insSetUp(double originTime, stampedSample& posit)
{
    cerr << "    Initializing INS." << endl;
    signal (SIGFPE, fpeInsSetUp);

    sam1.initSampler();          // Initialize the sampler
    sam1.getSample(posit);

    cerr << "    X accel = " << posit.sample[0]
        << ", Y accel = " << posit.sample[1]
        << ", Z accel = " << posit.sample[2] << endl;

    calculateBiasCorrections(posit);    // set imu biases

    posture[5] = posit.sample[7]; //set initial true heading

    buildRotationMatrix();              //set initial speed
    transformWaterSpeed(posit.sample[6], velocities);

    posit.current[0] = current[0];
    posit.current[1] = current[1];
    posit.current[2] = current[2];

    lastGPStime = originTime;           // initialize times

    cerr << "    INS initialization complete." << endl;
}

/*****
PROGRAM:      transformAccels
AUTHOR:       Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Transforms linear accelerations from body coordinates to
              earth coordinates and removes the gravity component in the z
              direction.
RETURNS:      void
CALLED BY:    navPosit
CALLS:        none
*****/

```

```

void insClass::transformAccels (double newSample[])
{
    vector earthAccels;

    newSample[0] -= GRAVITY * sin(posture[4]);
    newSample[1] += GRAVITY * sin(posture[3]) * cos(posture[4]);
    newSample[2] += GRAVITY * cos(posture[3]) * cos(posture[4]);

    earthAccels = rotationMatrix * newSample;

    newSample[0] = earthAccels.element[0];
    newSample[1] = earthAccels.element[1];
    newSample[2] = earthAccels.element[2];
}

/*****
PROGRAM:      transformWaterSpeed
AUTHOR:      Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Transforms water speed into a vector in earth
coordinates and returns them in the speedCorrection variable.
RETURNS:     void
CALLED BY:   navPosit
CALLS:       none
*****/

void insClass::transformWaterSpeed (double waterSpeed, double
speedCorrection[])
{
    double water[3] = {waterSpeed, 0.0, 0.0};
    vector waterVelocities = rotationMatrix * water;

    speedCorrection [0] = waterVelocities.element[0];
    speedCorrection [1] = waterVelocities.element[1];
    speedCorrection [2] = waterVelocities.element[2];
}

/*****
PROGRAM:      transformBodyRates
AUTHOR:      Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Transforms body euler rates to earth euler rates
RETURNS:     none
CALLED BY:   insPosit
CALLS:       buildBodyRateMatrix
*****/

void insClass::transformBodyRates (double newSample[])
{
    matrix bodyRateMatrix = buildBodyRateMatrix( );
    vector earthRates = bodyRateMatrix * &(newSample[3]);

    newSample[3] = earthRates.element[0];
    newSample[4] = earthRates.element[1];
    newSample[5] = earthRates.element[2];
}

```

```

/*****
PROGRAM:    buildBodyRateMatrix
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Builds body to Euler rate translation matrix.
RETURNS:     rate translation matrix
CALLED BY:   insPosit
CALLS:       none
*****/

```

```

matrix insClass::buildBodyRateMatrix()

```

```

{
    matrix rateTrans;

    float    tth = tan(posture[4]),
             sph = sin(posture[3]),
             cph = cos(posture[3]),
             cth = cos(posture[4]);

    rateTrans.element[0][0] = 1.0;
    rateTrans.element[0][1] = tth * sph;
    rateTrans.element[0][2] = tth * cph;
    rateTrans.element[1][0] = 0.0;
    rateTrans.element[1][1] = cph;
    rateTrans.element[1][2] = -sph;
    rateTrans.element[2][0] = 0.0;
    rateTrans.element[2][1] = sph / cth;
    rateTrans.element[2][2] = cph / cth;

    return rateTrans;
}

```

```

/*****
PROGRAM:    buildRotationMatrix
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Sets the body to earth coordinate rotation matrix.
RETURNS:     void
CALLED BY:   insPosit, insSetUp
CALLS:       none
*****/

```

```

void insClass::buildRotationMatrix()

```

```

{
    float spsi = sin(posture[5]),
          cpsi = cos(posture[5]),
          sth = sin(posture[4]),
          sph = sin(posture[3]),
          cph = cos(posture[3]),
          cth = cos(posture[4]);

    rotationMatrix.element[0][0] = cpsi * cth;
    rotationMatrix.element[0][1] = (cpsi * sth * sph) - (spsi * cph);
    rotationMatrix.element[0][2] = (cpsi * sth * cph) + (spsi * sph);
    rotationMatrix.element[1][0] = spsi * cth;
    rotationMatrix.element[1][1] = (cpsi * cph) + (spsi * sth * sph);
    rotationMatrix.element[1][2] = (spsi * sth * cph) - (cpsi * sph);
}

```

```

    rotationMatrix.element[2][0] = -sth;
    rotationMatrix.element[2][1] = cth * sph;
    rotationMatrix.element[2][2] = cth * cphi;
}

/*****
PROGRAM:      postmultiplication operator *
AUTHOR:       Eric Bachmann, Dave Gay
DATE:         11 July 1995
FUNCTION:      Post multiply a 3 X 3 matrix times a 3 X 1 vector and
return the result
RETURNS:      3 X 1 vector
CALLED BY:
CALLS:        None1
*****/

vector operator* (matrix& transform, double state[])
{
    vector result;

    for (int i = 0; i < 3; i++) {
        result.element[i] = 0.0;

        for (int j = 0; j < 3; j++) {
            result.element[i] += transform.element[i][j] * state[j];
        }
    }
    return result;
}

/*****
PROGRAM:      calculateBiasCorrections
AUTHOR:       Eric Bachmann, Dave Gay, Rick Roberts
DATE:         11 July 1995
FUNCTION:      Calculates the initial imu bias by averaging a number
of imu readings.
RETURNS:      none
CALLED BY:    insSetup
CALLS:        none
*****/

void fpeCalculateBiasCorrections(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
CalculateBiasCorrections\n";}

void insClass::calculateBiasCorrections(stampedSample& biasSample)
{
    signal (SIGFPE, fpeCalculateBiasCorrections);

    int biasNumber(tau/10);

    biasCorrection[0] = 0.0;           // p roll rate
    biasCorrection[1] = 0.0;           // q pitch rate
    biasCorrection[2] = 0.0;           // r yaw rate

```

```

for (int i = 0; i < biasNumber; i++) {

    // Find the average of the biasNumber packets
    while(!sam1.getSample(biasSample)) {/* */};

    // roll-rate/b#
    biasCorrection[0] += biasSample.sample[3]/biasNumber;
    // pitch-rate/b#
    biasCorrection[1] += biasSample.sample[4]/biasNumber;
    // yaw-rate/b#
    biasCorrection[2] += biasSample.sample[5]/biasNumber;
}

// set biasSample correction fields to new bias correction values
// negative biasCorrection value is taken so biases are added to
// sensor values
biasSample.bias[0] = biasCorrection[0] = -(biasCorrection[0]);
biasSample.bias[1] = biasCorrection[1] = -(biasCorrection[1]);
biasSample.bias[2] = biasCorrection[2] = -(biasCorrection[2]);
}

/*****
PROGRAM:      applyBiasCorrections
AUTHOR:      Eric Bachmann, Dave Gay, Rick Roberts
DATE:        11 July 1995
FUNCTION:     Applies updated bias corrections to a sample.
RETURNS:     void
CALLED BY:   insPosit
CALLS:       none
*****/

void insClass::applyBiasCorrections(stampedSample& posit)
{
    const float sampleWght(posit.deltaT/tau);
    const float biasWght(1 - sampleWght);

    //Calculate updated bias values
    biasCorrection[0] = (biasWght * biasCorrection[0])
        - (sampleWght * posit.sample[3]);
    biasCorrection[1] = (biasWght * biasCorrection[1])
        - (sampleWght * posit.sample[4]);
    biasCorrection[2] = (biasWght * biasCorrection[2])
        - (sampleWght * posit.sample[5]);

    //Apply the bias to the sample
    posit.sample[3] += biasCorrection[0];
    posit.sample[4] += biasCorrection[1];
    posit.sample[5] += biasCorrection[2];

    //Save the bias to the sample
    posit.bias[0] = biasCorrection[0];
    posit.bias[1] = biasCorrection[1];
    posit.bias[2] = biasCorrection[2];
}

```

```

/*****
PROGRAM:  readInsConfigFile
AUTHOR:   Rick Roberts, Eric Bachmann
DATE:     02 Nov 96
FUNCTION:  Reads filter constants from 'ins.cfg'
RETURNS:  void
CALLED BY: ins class constructor
CALLS:    none
*****/

void insClass::readInsConfigFile()
{
    cerr << "Reading ins configuration file." << endl;
    ifstream insCfgFile("ins.cfg", ios::in);

    if(!insCfgFile) {
        cerr << "could not open ins configuration file!" << endl;
    }
    else {
        char comment[128];
        insCfgFile
            >> Kone1 >> comment
            >> Kone2 >> comment
            >> Ktwo >> comment
            >> Kthree1 >> comment
            >> Kthree2 >> comment
            >> Kfour1 >> comment
            >> Kfour2 >> comment
            >> tau >> comment
            >> speed >> comment
            >> current[0] >> comment
            >> current[1] >> comment
            >> current[2] >> comment;

        cout << "\nKone1: " << Kone1 << "\nKone2: " << Kone2
            << "\nKtwo: " << Ktwo << "\nKthree1: " << Kthree1
            << "\nKthree2: " << Kthree2 << "\nKfour1: " << Kfour1
            << "\nKfour2: " << Kfour2 << "\ntau: " << tau
            << "\nx Current: " << current[0] << "\ny Current: "
            << current[1] << "\nz Current: " << current[2] << endl;
    }

    insCfgFile.close( );
}

/*****
PROGRAM:  constructHmatrix()
AUTHOR:   Kadir Akyol
DATE:     01 March 1999
FUNCTION:  constructs h matrix
RETURNS:  none
CALLED BY: ins class constructor
CALLS:    none
*****/

```

```

void fpeconstructHmatrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
constructHmatrix\n";}

void insClass::constructHmatrix()
{
    signal (SIGFPE, fpeconstructHmatrix);

    h.copy(0,0,1.0);
    h.copy(1,1,1.0);
    h.copy(2,4,1.0);
    h.copy(2,6,1.0);
    h.copy(3,5,1.0);
    h.copy(3,7,1.0);

    return ;
} //end constructHmatrix()

/*****
PROGRAM:    constructPminusMatrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs P_minus matrix
RETURNS:     none
CALLED BY:  ins class constructor
CALLS:       none
*****/

void fpeconstructPminusMatrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
constructPminusMatrix\n";}

void insClass::constructPminusMatrix()
{
    signal (SIGFPE, fpeconstructPminusMatrix);

    p_minus.copy(0,0,0.5);
    p_minus.copy(1,1,0.5);
    p_minus.copy(2,2,1.0);
    p_minus.copy(3,3,1.0);
    p_minus.copy(4,4,3.0);
    p_minus.copy(5,5,3.0);
    p_minus.copy(6,6,5.0);
    p_minus.copy(7,7,5.0);

    return ;
} //end constructPminusMatrix()

/*****
PROGRAM:    constructRlmatrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs rl matrix
RETURNS:     none
CALLED BY:  ins class constructor
CALLS:       none
*****/

```

```

void fpeconstructR1matrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
constructR1matrix\n";}

void insClass::constructR1matrix()
{
    signal (SIGFPE, fpeconstructR1matrix);

    r1.copy(0,0,0.5);
    r1.copy(1,1,0.5);

    return ;

}

//end constructR1Matrix()

/*****
PROGRAM:    constructH1matrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs h matrix
RETURNS:     none
CALLED BY:  ins class constructor
CALLS:       None
*****/

void fpeconstructH1matrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
constructH1matrix\n";}

void insClass::constructH1matrix()
{
    signal (SIGFPE, fpeconstructH1matrix);

    h1.copy(0,0,1.0);
    h1.copy(1,1,1.0);

    return ;

}

//end constructH1matrix()

/*****
PROGRAM:    constructR2matrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs r2 matrix
RETURNS:     none
CALLED BY:  ins class constructor
CALLS:       None
*****/

void fpeconstructR2matrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
constructR2matrix\n";}

void insClass::constructR2matrix()
{
    signal (SIGFPE, fpeconstructR2matrix);

```

```

        r2.copy(0,0,0.5);
        r2.copy(0,1,0.0);
        r2.copy(1,0,0.0);
        r2.copy(1,1,0.5);

        return ;

} //end constructR2atrix()

/*****
PROGRAM:    constructPhiMatrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs phi matrix
RETURNS:    none
CALLED BY:  insPosit
CALLS:      None
*****/

void fpeconstructPhiMatrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
cunstructPhiMatrix\n";}

void insClass::constructPhiMatrix(stampedSample& delta)
{
    signal (SIGFPE, fpeconstructPhiMatrix);

    double tau_1 = 60.0;
    double tau_3 = 3600.0;

    double xx, yy;

    xx = - (delta.deltaT)/tau_1;
    xx = exp(xx);
    yy = - (delta.deltaT)/tau_3;
    yy = exp(yy);

    phi.copy(0,0,xx);
    phi.copy(1,1,xx);
    phi.copy(2,2,xx);
    phi.copy(3,3,xx);
    phi.copy(4,4,yy);
    phi.copy(5,5,yy);
    phi.copy(6,0,((1-xx)*tau_1));
    phi.copy(6,2,((1-xx)*tau_1));
    phi.copy(7,1,((1-xx)*tau_1));
    phi.copy(7,3,((1-xx)*tau_1));

    return ;

} //end constructPhiMatrix()

```

```

/*****
PROGRAM:    constructqMatrix()
AUTHOR:     Kadir Akyol
DATE:       01 March 1999
FUNCTION:    constructs Q matrix
RETURNS:     none
CALLED BY:  insPosit
CALLS:       None
*****/

void fpeconstructqMatrix(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
cunstructqMatrix\n";}

void insClass::constructqMatrix(stampedSample& delt)
{

    signal (SIGFPE, fpeconstructqMatrix);

    double tau_1 = 60.0;
    double tau_3 = 3600.0;
    double zz, ww;

    zz = -(2.0 * delt.deltaT)/tau_1;
    zz = exp(zz);
    ww = -(2.0 * delt.deltaT)/tau_3;
    ww = exp(ww);

    q.copy(0,0,((1.0-zz)*(1.0/(2.0*tau_1))));
    q.copy(1,1,((1.0-zz)*(1.0/(2.0*tau_1))));
    q.copy(2,2,((1.0-zz)*(1.0/(2.0*tau_1))));
    q.copy(3,3,((1.0-zz)*(1.0/(2.0*tau_1))));
    q.copy(4,4,((1.0-ww)*(1.0/(2.0*tau_3))));
    q.copy(5,5,((1.0-ww)*(1.0/(2.0*tau_3))));

    return ;

} //end constructqMatrix()

//end of ins.cpp

```

I. SAMPLER.H

```
#ifndef _SAMPLER_H
#define _SAMPLER_H

#include <time.h>
#include <math.h>
#include <dos.h>
#include <conio.h>
#include <stdio.h>
#include <fstream.h>
#include <iostream.h>

#include "toetypes.h"
#include "globals.h"
#include "crb.h"
#include "atod.h"
#include "compass.h"

#define MAX_SAMPLE_NUM 1000
#define xyAccelLimit ONE_G           // Max accel in x and y direction
#define zAccelLimit 2 * ONE_G        // Max accel in z direction
#define rateLimit 0.872665           // Max rotational rate in radians
#define speedLimit 25.3              // Max water speed
#define headingLimit 2 * M_PI

const int INBUFFSIZE = 512;

/*****
CLASS:      samplerClass
AUTHOR:     Eric Bachmann, Dave Gay, Rick Roberts, Kadir Akyol
DATE:       11 July 1995, last modified March 1999
FUNCTION:    Formats, timestamps, low pass filters and limit checks
IMU, water-speed and heading information.
COMMENTS:    This class is extremely dependent upon the specific
hardware configuration. It is designed to isolate the INS from
these particulars.
*****/

class samplerClass {

public:

    samplerClass();           // Class constructor, destructor
    ~samplerClass() {}

    Boolean initSampler();     // Initializes Sampler

    // checks for the arrival of a new sample and formats it
    Boolean getSample(stampedSample&);

private:

    float pScale;             // roll
    float qScale;             // pitch
    float rScale;             // yaw
```

```

float xAccelScale;           // pitch
float yAccelScale;           // roll
float zAccelScale;           // yaw

float waterSpeedScale;

float voltage,speed;
double adOut;

atodClass ad;

compassClass compl;          // instantiate member compass object

crbClass crossbow1;          // instantiate member a2d object

long lastImuTime ;

int subSampleIndex;          // counts channels

int sampleIndex;             // indexes samples' array

int sampleCount;             // counts samples

float samplePeriod;

Boolean readSamples(stampedSample& newSample);

void formatSample(stampedSample& newSample);

void increment(int& index)
{ if (++index == MAX_SAMPLE_NUM) index = 0;}

void decrement(int& index)
{ if (--index < 0) index = MAX_SAMPLE_NUM - 1;}

// Reads filter constants from 'sam.cfg'
void readSamplerConfigFile( );

double pUnits(double angular)
{ return  (pScale * angular * ((50.0 * 1.5)/32768.0) *
(M_PI/180.0));}

double qUnits(double angular)
{ return  (qScale * angular * ((50.0 * 1.5)/32768.0) *
(M_PI/180.0));}

double rUnits(double angular)
{ return  (rScale * angular * ((50.0 * 1.5)/32768.0) *
(M_PI/180.0));}

double xAccelUnits(double linear)
{ return  (xAccelScale * ((linear * 2.0 * 1.5 *
GRAVITY)/32768.0));}

double yAccelUnits(double linear)
{ return  (yAccelScale * ((linear * 2.0 * 1.5 *
GRAVITY)/32768.0));}

```

```
double zAccelUnits(double linear)
{ return (zAccelScale * ((linear * 2.0 * 1.5 *
GRAVITY)/32768.0));}

};
#endif
```

J. SAMPLER.CPP

```
#include "sampler.h"

/*****
PROGRAM:    samplerClass Constructor
AUTHOR:     Eric Bachmann, Randy Walker, Rick Roberts, Kadir Akyol
DATE:       12 May 1995, last modified March 1999
FUNCTION:    Constructs sam1, initializes default config values, calls
readSamplerConfigFile to read any updated values.
RETURNS:     sam1
CALLED BY:   insSetUp (ins.cpp)
CALLS:       readSamplerConfigFile
*****/

samplerClass::samplerClass()
: sampleIndex(0), subSampleIndex(0),
  pScale(0.0), qScale(0.0), rScale(0.0),
  xAccelScale(0.0), yAccelScale(0.0), zAccelScale(0.0),
  waterSpeedScale(0.0), lastImuTime(0.0)
{
    cerr << "\nconstructing sampler w/ a2d1, comp1" << endl;
    readSamplerConfigFile();
}

/*****
PROGRAM:    initSampler
AUTHOR:     Eric Bachmann, Randy Walker, Rick Roberts, Kadir Akyol
DATE:       12 May 1995 last modified March 1999
FUNCTION:    Instantiates the compass A2D objects.
RETURNS:     TRUE
CALLED BY:   insSetUp (ins.cpp)
CALLS:       initCompass(), AtoD member functions
*****/

Boolean samplerClass::initSampler()
{
    sampleIndex = 0;
    subSampleIndex = 0;

    cerr << "      Initializing Sampler" << endl;

    comp1.initCompass();

    cerr << "      Initializing A2D." << endl;

    ad.Initatod(); //ben

    cerr << "      A2D initialization complete." << endl;

    cerr << "      Sampler initialization complete." << endl;

    return TRUE;
}
```

```

/*****
PROGRAM:    getSample
AUTHOR:     Eric Bachmann, Dave Gay, Kadir Akyol
DATE:       11 July 1995 last modified March 1999
FUNCTION:    Prepares raw sample data for use by the INS  object
RETURNS:     TRUE, if a valid sample was obtained
CALLED BY:   insPosit (ins)      insSetup (ins)
CALLS:       readSamples (sampler)
              filterSample (sampler)
              formatSample (sampler)
*****/

```

```

Boolean samplerClass::getSample(stampedSample& newSample)
{
    if (readSamples(newSample)) { // checks for the arrival of a new
sample

        formatSample(newSample);

        return TRUE;
    }

    return FALSE;                // Sample packet not available
}

```

```

/*****
PROGRAM:    readSamples
AUTHOR:     Eric Bachmann, Randy Walker
DATE:       12 May 1996
FUNCTION:    Retrieves all samples of the IMU, water speed, and depth
that are present in the A2D FIFO until the FIFO is EMPTY. Calculates
delta_t.
RETURNS:     TRUE - There were new samples pulled from the FIFO
FALSE - There were no new samples
CALLED BY:   getSample
CALLS:       StartConversion(), ConversionDone(), ReadData();
*****/

```

```

Boolean samplerClass::readSamples(stampedSample& newSample)
{
    if (crossbow1.crbPosition(newSample.crossbowData)) {

        long newImuTime, timeDiff;

        newImuTime =
(newSample.crossbowData[19]*256+newSample.crossbowData[20]);

        if (newImuTime < 0){

            newImuTime += 65536;
        } //end if

        if (lastImuTime != 0){

            if(lastImuTime < newImuTime){

```

```

        timeDiff = 65536 - newImuTime + lastImuTime;
    }
    else {

        timeDiff = lastImuTime - newImuTime;
    }

    newSample.deltaT = 0.00000079 * (double)timeDiff;

}
else {

    newSample.deltaT = 0.05;
}

lastImuTime = newImuTime ;

//atod converter to read speed voltage
ad.StartConversion();

//wait until conversion done
while (ad.ConversionDone()== 0){};

//read the converted value
adOut = ad.ReadData();

if(adOut>2047){

    adOut = adOut - 4096;
} //end if

voltage = (adOut * 0.00244) ;
newSample.sample[6] = (-7.64/voltage);

return TRUE;
}
else {

    return FALSE;
}
}

/*****
PROGRAM:    formatSample
AUTHOR:    Eric Bachmann, Dave Gay, Kadir Akyol
DATE:      11 July 1995 last modified March 1999
FUNCTION:   Converts integers representing voltage readings into
real world units which are useable by the INS.
RETURNS:    void
CALLED BY:  getSample
CALLS:      none
*****/

void samplerClass::formatSample (stampedSample& newSample)
{
    newSample.sample[0] =
    (newSample.crossbowData[11]*256.0+newSample.crossbowData[12]);

```

```

    if( newSample.sample[0] > 32767.0 ){
        newSample.sample[0] -= 65536.0 ;
    }

    newSample.sample[0] = xAccelUnits(newSample.sample[0]);

    newSample.sample[1] =
(newSample.crossbowData[13]*256.0+newSample.crossbowData[14]);

    if( newSample.sample[1] > 32767.0 ){
        newSample.sample[1] -= 65536.0 ;
    }

    newSample.sample[1] = yAccelUnits(newSample.sample[1]);

    newSample.sample[2] =
(newSample.crossbowData[15]*256.0+newSample.crossbowData[16]);

    if( newSample.sample[2] > 32767.0 ){
        newSample.sample[2] -= 65536.0 ;
    }

    newSample.sample[2] = zAccelUnits(newSample.sample[2]);

    newSample.sample[3] =
(newSample.crossbowData[5]*256.0+newSample.crossbowData[6]);

    if( newSample.sample[3] > 32767.0 ){
        newSample.sample[3] -= 65536.0 ;
    }

    newSample.sample[3] = pUnits(newSample.sample[3]);

    newSample.sample[4] =
(newSample.crossbowData[7]*256.0+newSample.crossbowData[8]);

    if( newSample.sample[4] > 32767.0 ){
        newSample.sample[4] -= 65536.0 ;
    }

    newSample.sample[4] = qUnits(newSample.sample[4]);

    newSample.sample[5] =
(newSample.crossbowData[9]*256.0+newSample.crossbowData[10]);

    if( newSample.sample[5] > 32767.0 ){
        newSample.sample[5] -= 65536.0 ;
    }

```

```

    newSample.sample[5] = rUnits(newSample.sample[5]);

    newSample.sample[7] = compl.getHeading();
}

/*****
PROGRAM:    readSamplerConfigFile
AUTHOR:    Rick Roberts, Eric Bachmann
DATE:      02 Nov 96
FUNCTION:   Reads filter constants from 'ins.cfg'
RETURNS:    void
CALLED BY:  ins class constructor
CALLS:      none
COMMENTS:   * Do not allow blanks in 'comment' section of sam.cfg *
*****/

void samplerClass::readSamplerConfigFile()
{
    FILE *samCfgFile;

    if ((samCfgFile = fopen("sam.cfg", "r")) == NULL){
        cerr << "could not open sampler configuration file!" << endl;
    }
    else {
        cerr << "\nReading Sampler configuration file." << endl;

        char line[128];

        fscanf(samCfgFile,"%f%s",&pScale,line);
        cerr << "pScale: " << pScale << endl;

        fscanf(samCfgFile,"%f%s",&qScale,line);
        cerr << "qScale: " << qScale << endl;

        fscanf(samCfgFile,"%f%s",&rScale,line);
        cerr << "rScale: " << rScale << endl;

        fscanf(samCfgFile,"%f%s",&xAccelScale,line);
        cerr << "xAccelScale: " << xAccelScale << endl;

        fscanf(samCfgFile,"%f%s",&yAccelScale,line);
        cerr << "yAccelScale: " << yAccelScale << endl;

        fscanf(samCfgFile,"%f%s",&zAccelScale,line);
        cerr << "zAccelScale: " << zAccelScale << endl;

    }

    fclose(samCfgFile);
}
// end of file sampler.cpp

```

K. COMPASS.H

```
#ifndef _MCOMPASS_H
#define _MCOMPASS_H

#include <iostream.h>
#include <fstream.h>
#include <conio.h>
#include "toetypes.h"

BYTE asciiToHex(BYTE);          // conversion function prototype

/*****
CLASS:      compassClass
AUTHOR:     Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995, last modified January 1997
FUNCTION:    Reads compass messages from the compass buffer. Checks for
valid checksum. Corrects heading for magnetic variation. Heading is
continuous. There is no branch cut at 360 degrees.
*****/

class compassClass {

public:

    // class constructor and destructor
    compassClass() : currentHeading(0.0)
    {
        cerr << "Compass constructed." << endl;
    }
    ~compassClass() {}

    float initCompass();          // initialize currentHeading

    float getHeading();           // returns the latest heading

private:
    // Maintains the most recently obtained heading.
    float currentHeading;

    // Maintains the compass headings due to deviation float
    compassHeading[38];

    // calculates the check sum of the message
    Boolean checksumCheck(const compData);

    // Parses a selected field out of a compass message.
    float parseCompData(const compData, const BYTE);

    // Returns the heading without branch cuts
    float continousHeading(const float);

    // Converts magnetic direction based on magnetic variation.
    float trueHeading(const float);

};
#endif
```

L. COMPASS.CPP

```
#include <math.h>
#include <stdlib.h>
#include "compass.h"
#include "compport.h"

// instantiates serial port communications on comm2, global to allow
// interrupt processing, cleanup to function correctly
compassPortClass port2;

/*****
NAME:      initCompass
AUTHOR:    Eric Bachmann, Dave Gay, Rick Roberts
DATE:      11 July 1995
FUNCTION:   Determines if a valid compass message is held in the
compass buffer and initializes currentHeading to that value. Will
attempt 10 times with a built in delay and then exit with a warning
if a valid heading is not obtained.
RETURNS:    currentHeading
CALLED BY:  INSsetUp (ins.cpp)
CALLS:      Get (buffer.h), parseCompData (compass.cpp),
            checksumCheck (gps.h), continuousHeading (compass.cpp),
            trueHeading (compass.cpp)
*****/

float compassClass::initCompass()
{
    cerr << "      Initializing Compass" << endl;

    Boolean compFlag(FALSE);
    float tempHeading;
    compData rawMessage;

    // try 10 times to get a valid message
    for (int i = 1 ; ((i < 10) && (compFlag == FALSE)); i++ ) {

        if ((port2.headings.Get(rawMessage)) &&
            (checksumCheck(rawMessage))) {
            tempHeading = parseCompData(rawMessage, 'C') * degToRad;
            currentHeading = continuousHeading(trueHeading(tempHeading));
            compFlag = TRUE;
        }
        else {
            // invalid message - delay
            delay(1000);
        }
    }

    if (compFlag == FALSE) {
        cerr << "\nWARNING: UNABLE TO OBTAIN INITIAL COMPASS HEADING!"
        << endl;
        delay(2000);
    }
    else {
        cerr << "      Compass initialization complete." << endl;
    }
}
```

```

return currentHeading;
}

/*****
NAME:      getHeading
AUTHOR:    Eric Bachmann, Dave Gay, Rick Roberts
DATE:      11 July 1995
FUNCTION:   Determines if an updated compass message is available and
copies it into the input argument 'rawMessage'. If the message has a
valid checksum, currentHeading is returned to the caller,
currentHeading is also the default return.
RETURNS:   currentHeading
CALLED BY: navPosit (navigator.h)
CALLS:     Get (buffer.h)      checksumCheck (compass.cpp)
*****/

float compassClass::getHeading()
{
    float tempHeading;
    compData rawMessage;

    if ((port2.headings.Get(rawMessage)) && (checksumCheck(rawMessage))) {

        tempHeading = parseCompData(rawMessage, 'C') * degToRad;
        currentHeading = continousHeading(trueHeading(tempHeading));

        return currentHeading;
    }
    else {
        return currentHeading;    // No updated position is available.
    }
}

/*****
NAME:      asciiToHex
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Administrative conversion function
RETURNS:   Hex version of an ascii character
CALLED BY: checksumCheck
CALLS:     None
*****/

BYTE asciiToHex(BYTE letter)
{
    if (letter >= 'A') {
        return (letter - 'A' + 10);
    }
    else {
        return (letter - 48);
    }
}

```

```

/*****
PROGRAM:   checksumCheck
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Calculates the checksum of the compass message and
compares it to the indicated checksum of the message.
RETURNS:    TRUE, if the message contains a valid checksum
CALLED BY:  initCompass, getHeading
CALLS:      none
*****/

```

```

Boolean compassClass::checksumCheck(const compData newMessage)
{
    BYTE calChkSum(0);
    BYTE mesChkSum(0);
    int i;

    for (i = 1; newMessage[i] != '*'; i++) {
        calChkSum ^= newMessage[i];
    }

    mesChkSum = asciiToHex(newMessage[i+1]) * 16
                + asciiToHex(newMessage[i+2]);

    return Boolean(calChkSum == mesChkSum);
}

```

```

/*****
PROGRAM:   trueHeading
AUTHOR:    Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Converts magnetic direction to true based on local
magnetic variation.
RETURNS:    true heading
CALLED BY:  insPosit, insSetUp
CALLS:      none
*****/

```

```

float compassClass::trueHeading(const float magHeading)
{
    static double twoPi(2.0 * M_PI);
    double trueHeading = magHeading + RADIANMAGVAR;

    if (trueHeading > twoPi) {
        trueHeading -= twoPi;
    }

    return trueHeading;
}

```

```

/*****
PROGRAM:      continousHeading
AUTHOR:       Eric Bachmann
DATE:        11 July 1995
FUNCTION:     Maintains track of branch cuts and returns a continous
heading.
RETURNS:      continous true heading
CALLED BY:    insPosit, insSetUp
CALLS:        none
*****/

```

```

float compassClass::continousHeading(const float trueHeading)
{
    const float twoPi(2.0 * M_PI);
    static int branchCutCount(0);
    static float previousHeading(trueHeading);

    if ((4.71 < previousHeading) && (trueHeading < 1.57)){
        ++branchCutCount; // Went through North in a right hand turn
    }
    else {
        if ((1.57 > previousHeading) && (trueHeading > 4.71)) {
            --branchCutCount; // Went through North in a left hand turn
        }
    }

    previousHeading = trueHeading;

    return trueHeading + (branchCutCount * twoPi);
}

```

```

/*****
PROGRAM:      parseCompData
AUTHOR:       Eric Bachmann
DATE:        11 July 1995
FUNCTION:     Parses the heading out of a compass message.
RETURNS:      the message heading as a float
CALLED BY:    insPosit, insSetUp
CALLS:        none
*****/

```

```

float compassClass::parseCompData(const compData rawMessage, const BYTE
key)
{
    float dataSum(0);
    int j,i;

    for(j = 0; rawMessage[j] != key; j++){

        j++;

        for(i = 0; rawMessage[i + j] != '.'; i++){

            switch (i) {

                case 3:

```

```

    dataSum = (rawMessage[j] - 48) * 100.0 +
               (rawMessage[j+1] - 48) * 10.0 +
               (rawMessage[j+2] - 48) + (rawMessage[j+4] - 48) * 0.1;
    break;

    case 2:

    dataSum = (rawMessage[j] - 48) * 10.0 +
               (rawMessage[j+1] - 48) + (rawMessage[j+3] - 48) * 0.1;
    break;

    case 1:

    dataSum = (rawMessage[j] - 48) + (rawMessage[j+2] - 48) * 0.1;

    break;
}

return dataSum;
}

// end of file compass.cpp

```

M. CRB.H

```
#ifndef _CRB_H
#define _CRB_H

#include <iostream.h>
#include <fstream.h>
#include <conio.h>

#include "toetypes.h"
#include "globals.h"
#include "crbPort.h"

/*****
  CLASS:      crbClass
  AUTHOR:     Kadir Akyol, Erich Bachmann
  DATE:       03 November 1998
  FUNCTION:   Reads Crossbow messages from the Crossbow buffer. Checks
              for valid checksum.
*****/

class crbClass {

public:

    // Class constructor and destructor
    crbClass() { cerr << "\nconstructing crossbow" << endl; };
    ~crbClass() {}

    // returns the latest crossbow message
    Boolean crbPosition(CRBdata&);

private:

    // calculates the check sum of the message
    Boolean checksumCheck(const CRBdata);

};

#endif
```

N. CRB.CPP

```
#include <math.h>
#include "crb.h"

// instantiates serial port communications on comm3, global to allow
// interrupt processing, cleanup to function properly
crbPortClass port3;

/*****
NAME:      crbPosition
AUTHOR:    Kadir Akyol, Erich Bachmann
DATE:      03 November 1998
FUNCTION:   Determines if an updated crb message is available and
copies it into the input argument 'rawMessage'. If the message
has a valid checksum 'TRUE' is returned to the caller, indicating
that the message is valid.
RETURNS:    TRUE, if a valid position message is contained in the
            input argument.
CALLED BY:  navPosit (navigator.h)
CALLS:      Get (buffer.h)
            checksumCheck (crb.h)
*****/

Boolean crbClass::crbPosition(CRBdata& rawMessage)
{
    Boolean validFlag(TRUE);
    //unsigned long Mask(4);

    if (port3.Get(rawMessage)) {

        // Check for a valid check sum
        if (!checksumCheck(rawMessage)) {
            //cerr << "bad checksum" << endl;
            validFlag = FALSE;
        } //end if

        return validFlag;
    }
    else {
        return FALSE;                // No updated message is available.
    } //end if-else
} //end crbPosition

/*****
PROGRAM:    checksumCheck
AUTHOR:     Kadir Akyol, Erich Bachmann
DATE:       03 November 1998
FUNCTION:    Adds of bytes 2 through 21 in a Crossbow DMU-VG mode
            messages, compute checksum and compares it to the
            checksum of the message.
RETURNS:     TRUE, if the message contains a valid checksum
CALLED BY:   crbPosition (gps)
CALLS:       none
*****/
```

```
Boolean crbClass::checkSumCheck(const CRBdata newMessage)
{
    BYTE chkSum(0);

    for (int i = 1; i < CRBBLOCKSIZE - 1; i++) {
        chkSum += newMessage[i];
    }

    chkSum = chkSum % 256;

    return Boolean(chkSum == newMessage[CRBBLOCKSIZE - 1]);
}
// end of file crb.cpp
```

O. MATRIX.H

```
#ifndef __MATRIX_H__
#define __MATRIX_H__

#include <iostream.h>
#include <iomanip.h>

/*****
CLASS:      Matrix
AUTHOR:     Kadir Akyol, Ildeniz Duman
DATE:       09 January 1999
FUNCTION:    Executes matrix operations.
*****/

class Matrix{

    // overloaded operator<<
    friend ostream &operator<<(ostream &,const Matrix &);

public:

    // default constructor
    Matrix (char * mname="Matrix",int mrow = 4,int mcol = 4);

    //conversion constructor from a two dimensional double array
    Matrix (char * mname,int arrayRow, int arrayCol,double **);

    // destructor
    ~Matrix();

    // copy constructor
    Matrix (const Matrix &);

    // matrix inversion
    Matrix invert();

    // transpose
    void transpose (Matrix &) const;

    // Matrix product
    Matrix operator*(const Matrix &) const;

    // Matrix addition
    Matrix operator+(const Matrix &) const;

    // Matrix subtraction
    Matrix operator-(const Matrix &) const;

    // Matrix assignment
    Matrix &operator=(const Matrix &);

    // Matrix product and assignment
    Matrix &operator*=(const Matrix &);

    // creates a unit matrix
```

```

    Matrix unitMatrix(int);

void copy(int , int ,double );

// return row no
int getRow(){return row;}

// return col no
int getCol(){return col;}

// returns an element from the matrix
double getElement(int i, int j){ return matrix[i][j];}

private:

    // the name of the Matrix
    char * name;

    // the elements of a Matrix
    double ** matrix;

    //row and column
    int row, col;

};

#endif

// end of file Matrix.h

```

P. MATRIX.CPP

```
#include <math.h>
#include <string.h>
#include <assert.h>
#include <signal.h>
#include "Matrix.h"

#define SIGFPE 8

/*****
NAME:      Matrix Constructor
AUTHOR:    Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Default constructor
RETURNS:    None
CALLED BY:  insClass (ins.cpp)
CALLS:      None
*****/

Matrix::Matrix (char* mname,int mrow, int mcol)
:row(mrow),col(mcol)
{
    int length = strlen(mname);
    name = new char[length+1];
    assert (name != 0);
    strcpy(name,mname);

    matrix = new double *[row];
    assert (matrix !=0);

    for (int x = 0; x<row; x++){
        matrix[x] = new double [col];
        assert (matrix[x] !=0);
    }
    for (int i = 0;i<row;i++){
        for (int j = 0;j<col;j++){
            matrix[i][j] = 0.0;
        }
    }
}

//end Constructor

/*****
NAME:      Matrix Destructor
AUTHOR:    Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Destructor
RETURNS:    None
CALLED BY:  None
CALLS:      None
*****/

Matrix::~Matrix()
{
    delete [] name;
    for (int x=0;x<row;x++){
```

```

        delete matrix[x];
    }
    delete [] matrix;
} //end destructor

/*****
NAME:      Matrix(Matrix &)
AUTHOR:    Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Copy constructor
RETURNS:    None
CALLED BY:  None
CALLS:      None
*****/

Matrix::Matrix(const Matrix &MAT)
{
    int length = strlen(MAT.name);

    name = new char[length+1];
    assert(name != 0);
    strcpy(name, MAT.name);
    matrix = new double *[MAT.row];
    assert (matrix !=0);
    for (int x = 0; x<MAT.row; x++){
        matrix[x] = new double [MAT.col];
        assert (matrix[x] !=0);
    }
    row=MAT.row;
    col=MAT.col;
    for (int i = 0; i<MAT.row; i++){
        for (int j = 0; j<MAT.col; j++){
            matrix[i][j] = MAT.matrix[i][j];
        }
    }
}

} // end copy constructor

/*****
NAME:      Matrix()
AUTHOR:    Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Constructs a matrix from a two dimensional array
RETURNS:    None
CALLED BY:  None
CALLS:      None
*****/

Matrix::Matrix (char * mname , int arow, int acol, double ** a)
{
    int length = strlen(mname);

    name = new char[length+1];
    assert (name != 0);
    strcpy(name, mname);
    matrix = new double *[arow];
    assert (matrix !=0);

```

```

    for (int x = 0; x<arow; x++){
        matrix[x] = new double [acol];
        assert (matrix[x] !=0);
    }
    row = arow;
    col = acol;
    for (int i = 0; i<row; i++){
        for (int j = 0; j<col; j++){
            matrix[i][j] = a[i][j];
        }
    }
}

} // end Matrix()

/*****
NAME:      operator*()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Calculates the Matrix product
RETURNS:    Matrix
CALLED BY:  insPosit (ins.cpp)
CALLS:      None
*****/

void fpeoperatorMul(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
fpeoperatorMul\n";}

Matrix Matrix::operator*(const Matrix &MAT) const
{
    signal (SIGFPE, fpeoperatorMul);

    Matrix dest("Product", row , MAT.col);
    double sum = 0.0f;
    for (int i=0; i<row; i++){
        for (int j=0; j<MAT.col; j++){
            for (int k=0; k<MAT.row; k++){
                sum += matrix[i][k] * MAT.matrix[k][j];
            }
            dest.matrix[i][j]=sum;
            sum = 0.0;
        }
    }

    return(dest);
} //end operator*

/*****
NAME:      operator=()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Assigns the MAT to current object
RETURNS:    Matrix &
CALLED BY:  insPosit (ins.cpp)
CALLS:      None
*****/

```

```

void fpeoperatorEqual(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
fpeoperatorEqual\n";}

Matrix & Matrix::operator=(const Matrix &MAT)
{
    signal (SIGFPE, fpeoperatorEqual);

    // I let self assingment
    if ((row!=MAT.row) || (col != MAT.col)){
        cout <<"Error in matrix assignment ";
    } else {
        delete [] name;
        int length = strlen(MAT.name);
        name = new char[length+1];
        assert(name != 0);

        for (int i = 0;i<MAT.row;i++){
            for (int j = 0;j<MAT.col;j++){
                matrix[i][j] = MAT.matrix[i][j];
            }
        }
        return (*this);
    }
}

/*****
NAME:      unitMatrix()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Creates a unit matrix
RETURNS:    Matrix
CALLED BY: insPosit (ins.cpp)
CALLS:      None
*****/

Matrix Matrix::unitMatrix (int rowOrCol)
{
    Matrix Unit("unit", rowOrCol , rowOrCol);

    for (int i = 0 ; i<Unit.row ; i++){
        Unit.matrix[i][i] = 1.0;
    }
    return (Unit);
}
// end unitMatrix()

/*****
NAME:      invert()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Calculates the matrix inversion
RETURNS:    Matrix
CALLED BY: insPosit (ins.cpp)
CALLS:      None
*****/

```

```

void fpeinvert(int sig)
{if (sig == SIGFPE) cerr << "floating point error in fpeinvert\n";}

Matrix Matrix::invert()
{
    signal (SIGFPE, fpeinvert);

    double multiplier=0.0 , divider =0.0;

    Matrix myUnit=myUnit.unitMatrix(row);

    // square matrix check
    if (row == col){

        //inverting the matrix
        for (int j=0; j<col;j++){
            for (int i=0; i<row;i++){
                if (i != j ){
                    multiplier = -matrix[i][j]/matrix[j][j];
                    for (int k=0;k<col;k++){
                        matrix[i][k] += (multiplier * matrix [j][k]);
                        myUnit.matrix[i][k] += (multiplier *
                                                myUnit.matrix[j][k]);
                    }
                }
            }
        }

        // final division to make our matrix a unit matrix
        for (int i = 0 ; i<row ; i++){
            divider = matrix[i][i];
            if (divider != 0.0){
                matrix [i][i] /= matrix [i][i];
                for (int k=0;k<myUnit.row;k++){
                    myUnit.matrix [i][k] /= divider;
                }
            }
        }
    } else {
        cout << "Error : Matrix must be a square matrix "<<endl;
    }
    return (myUnit);
}
// end unitMatrix()

/*****
NAME:      operator*=( )
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Calculates the product and assigns the result to
            current object
RETURNS:    Matrix
CALLED BY:  None
CALLS:      None
*****/

```

```

void fpeoperatorMulEqual(int sig)
{if (sig == SIGFPE) cerr << "floating point error in
fpeoperatorMulEqual\n";}

Matrix & Matrix::operator*=(const Matrix &MAT)
{
    signal (SIGFPE, fpeoperatorMulEqual);
    *this = *this * MAT;
    return (*this);
} // end operator*=

/*****
NAME:      transpose()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Finds the transpose of a matrix
RETURNS:    None
CALLED BY:  insPosit (ins.cpp)
CALLS:      None
*****/

void fpetranspose(int sig)
{if (sig == SIGFPE) cerr << "floating point error in fpetranspose\n";}

void Matrix::transpose(Matrix & tr) const
{
    signal (SIGFPE, fpetranspose);
    if ((row == tr.col) && (col == tr.row)){
        for (int i=0;i<row;i++){
            for (int j=0;j<col;j++){
                tr.matrix[j][i] = matrix[i][j];
            }
        }
    }

    return;
} // end transpose()

/*****
NAME:      operator<<()
AUTHOR:    Kadir Akyol, Ildeniz Duman
DATE:      01 January 1999
FUNCTION:   Prints the Matrix in a form, should be written out of
            class
RETURNS:    ostream object
CALLED BY:  None
CALLS:      None
*****/

ostream &operator<<(ostream &output, const Matrix &q)
{
    output << '[' << q.name << ']' << " " << q.row << "x" << q.col << endl;;

    for (int k=0;k<q.row;k++){
        for (int m=0;m<q.col;m++){
            output << "    " << q.matrix[k][m];
        }
    }
}

```

```

        output <<endl;
    }

    return output;
} // end operator<<

/*****
NAME:      operator+
AUTHOR:    Kadir Akyol
DATE:      01 January 1999
FUNCTION:   Calculates the Matrix addition
RETURNS:    Matrix
CALLED BY:  insPosit (ins.cpp)
CALLS:      None
*****/

void fpePlus(int sig)
{if (sig == SIGFPE) cerr << "floating point error in fpePlus\n";}

Matrix Matrix::operator+(const Matrix &MAT) const
{
    signal (SIGFPE, fpePlus);
    Matrix add("Addition", row , col);

    if ((row!=MAT.row) || (col != MAT.col)){
        cout <<"Error in matrix assignment ";
    }
    else {

        for (int i=0;i<row;i++){
            for (int j=0;j<col;j++){

                add.matrix[i][j] = matrix[i][j] + MAT.matrix[i][j];

            }

        }

    }

    return(add);
} //end operator+

/*****
NAME:      operator-
AUTHOR:    Kadir Akyol
DATE:      01 January 1999
FUNCTION:   Calculates the Matrix subtraction
RETURNS:    Matrix
CALLED BY:  insPosit (ins.cpp)
CALLS:      None
*****/

void fpeMinus(int sig)
{if (sig == SIGFPE) cerr << "floating point error in fpeMinus\n";}

```

```

Matrix Matrix::operator-(const Matrix &MAT) const
{
    signal (SIGFPE, fpeMinus);

    Matrix subt("Subtruction", row , col);

    if ((row!=MAT.row) || (col != MAT.col)){
        cout <<"Error in matrix assignment ";
    }
    else {
        for (int i=0;i<row;i++){
            for (int j=0;j<col;j++){

                subt.matrix[i][j] = matrix[i][j] - MAT.matrix[i][j];

            }
        }

    }

    return(subt);
}

//end operator-

/*****
NAME:      copy
AUTHOR:    Kadir Akyol
DATE:      01 January 1999
FUNCTION:   Copies the designated elementh of Matrix to a Matrix
RETURNS:    None
CALLED BY: insPosit (ins.cpp), constructHmatrix (ins.cpp),
            constructPminusMatrix (ins.cpp), constructR1matrix (ins.cpp),
            constructH1matrix (ins.cpp), constructR2matrix (ins.cpp),
            constructPhiMatrix (ins.cpp), constructqMatrix (ins.cpp)
CALLS:      None
*****/

void Matrix::copy(int row, int col,double a)
{
    matrix[row][col] = a;

    return;
}

//end of file copy

//end of file Matrix.cpp

```

APPENDIX B: SERIAL COMMUNICATION SOURCE CODE (C++)

A. GLOABAL.H

```
#ifndef _GLOBALS_H
#define _GLOBALS_H

#include <dos.h>

// types
typedef unsigned char BYTE;
typedef unsigned short WORD;
typedef unsigned long DWORD;

#define MEM(seg,ofs)      (*( (BYTE far*)MK_FP(seg,ofs)))
#define MEMW(seg,ofs)     (*( (WORD far*)MK_FP(seg,ofs)))

enum Boolean    {FALSE, TRUE};

// basic bit twiddles
#define set(bit)          (1<<bit)
#define setb(data,bit)    (data | set(bit))
#define clrb(data,bit)    (data & !set(bit))
#define setbit(data,bit)  (data = setb(data,bit))
#define clrbit(data,bit)  (data = clrb(data,bit))

// specific to ports
#define setportbit(reg,bit) (outportb(reg,setb(inportb(reg),bit)))
#define clrportbit(reg,bit) (outportb(reg,clrb(inportb(reg),bit)))

// navigation conversion factors and useful global variables
#define MSECs_TO_DEGREES (1.0/(1000.0 * 3600.0)) // time conversion
#define DEGREES_TO_MSECs 3600000.0
#define MINS_TO_MSECs 60000.0

// Conversion constants for location of 36:35:42.2N and 121:52:28.7W
#define LatToFt 0.10134 // converts degrees Latitude to ft
#define LongToFt 0.08156 // converts degrees Longitude to ft
#define HemisphereConversion -1 // -1 if west of Greenwich

#define RADIANMAGVAR 0.261799 //Local area Magnetic variation in rad

#define radToDeg (180.0/M_PI)
#define degToRad (M_PI/180.0)

#endif
```

B. BUFFER.H

```
#ifndef _BUFFER_H
#define _BUFFER_H

#include "toetypes.h"
#include "globals.h"

#define ONE (unsigned short)1

/*****
CLASS:      bufferClass
AUTHOR:     Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995
FUNCTION:    Base class for use as a polymorphic reference in the
serial port code which defines a buffer to be used in serial port
communications.
*****/

class bufferClass {

public:

    bufferClass(WORD sz);    //Constructor
    ~bufferClass() {}

    // Checks for the arrival of new characters in the buffer
    Boolean hasData() { return Boolean(putPtr != getPtr); }

    // How much of the Buffer is used (rounded percentage 0 - 100)
    int capacityUsed();

    Boolean Get(BYTE&);      // read from the buffer
    void Add(BYTE);          // write to the buffer

protected:

    // Increment the pointer to next position
    void inc(WORD& index) { if (++index == size) index = 0; }

    WORD before(WORD index)      // decrement the pointer
    { return ((index == 0) ? size - ONE : index - ONE); }

    WORD getPtr;                // Location of unread data
    WORD putPtr;                // Location to read data to
    WORD size;                  // Size of the buffer in bytes
    BYTE* buf;

};
#endif
```

C. BUFFER.CPP

```
#include <iostream.h>
#include <stdio.h>
#include "globals.h"
#include "buffer.h"

/*****
FUNCTION NAME:  bufferClass constructor
AUTHOR:        Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:         11 July 1995
DESCRIPTION:   Instantiates a buffer
RETURNS:      void
CALLS:        none
CALLED BY:    compBuffer, GPSbuffer, bufferedSerialPort constructors
*****/

bufferClass::bufferClass(WORD sz) : getPtr(0), putPtr(0), size(sz)
{
    buf = new BYTE[size];
}

/*****
FUNCTION NAME:  capacityUsed()
AUTHOR:        Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:         11 July 1995
DESCRIPTION:   Returns the rounded percentage of the buffer used.
RETURNS:      void
CALLS:        none
CALLED BY:    bufferedSerialPort::processInterrupt
*****/

int bufferClass::capacityUsed()
{
    int cap = (putPtr + size) % size - getPtr;
    return 100 * cap / size;
}

/*****
FUNCTION NAME:  Get
AUTHOR:        Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:         11 July 1995
DESCRIPTION:   Reads a character from the buffer
RETURNS:      Boolean
CALLS:        hasData()
CALLED BY:    GPSbufferClass, compBufferClass
*****/

Boolean bufferClass::Get(BYTE& data)
{
    if (hasData()) {
        data = buf[getPtr];
        inc(getPtr);
        return TRUE;
    }
    return FALSE;
}
```

```

/*****
FUNCTION NAME:  Add
AUTHOR:        Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:          11 July 1995
DESCRIPTION:    Writes a character to the buffer and checks for buffer
                overflow
RETURNS:        void
CALLS:          hasData
CALLED BY:      GPSbufferClass, compBufferClass
*****/

void bufferClass::Add(BYTE ch)
{
    buf[putPtr] = ch;
    inc(putPtr);

    // if there's no data after adding data, it overflowed
    if (!hasData()) {
        cerr << "\nError: byteBuffer overflow\n";
    }
}
// end of file buffer.cpp

```

D. GPSBUFF.H

```
#ifndef _GPSBUFF_H
#define _GPSBUFF_H

#include "globals.h"
#include "toetypes.h"
#include "buffer.h"

#define GPSBLOCKS      4
#define LINE_FEED      10
#define CARR_RETURN    13

/*****
Class buffers GPS position messages via serial port communications.
Uses a multiple buffer system in which each buffer is capable of
holding a single position message. Buffers are filled and processed
sequentially in a round robin fashion. Messages are checked for
validity only upon attempted reads from the buffer.
*****/

class gpsBufferClass : public bufferClass {

public:

    gpsBufferClass(BYTE GPSblocks = GPSBLOCKS);
    ~gpsBufferClass() { delete [] block; }

    Boolean  hasData();           // a complete structure is ready
    Boolean  Get(BYTE&) { return FALSE; }
    Boolean  Get(GPSdata);        // fill in a complete structure
    void     Add(BYTE ch);        // build the structure byte by byte

protected:

    Boolean  validHeader(GPSdata); // check a block for valid header
    GPSdata *block;              // hold the buffered GPS data
    WORD     current, last;       // current and last GPS block in use
    BYTE     *putPlace;           // for the next character received
};
#endif
```

E. GPSBUFF.CPP

```
#include <iostream.h>
#include <stdio.h>

#include "gpsbuff.h"

/*****
PROGRAM:      gpsBuffer (Constructor)
AUTHOR:      Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:     Allocates message buffers, indicate that no data has
              been received by equalizing current and last and set position into
              which initial character will be read.
RETURNS:     nothing.
CALLED BY:    navigator class (nav.h)
CALLS:       none.
*****/

gpsBufferClass::gpsBufferClass(BYTE GPSblocks) : current(0), last(0),
        bufferClass(GPSblocks) // Call to base class
constructor
{
    cerr << "constructing gpsBuffer" << endl;
    block = new GPSdata[GPSblocks]; // Create an array of GPSdata elements
    putPlace = &(block[current][0]); // Set the place for the first
character
}

/*****
PROGRAM:      Add
AUTHOR:      Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:     Interrupt driven routine which writes incoming
              characters into the gps buffers
RETURNS:     nothing.
CALLED BY:    interrupt driven by bufferedSerialPort
CALLS:       none.
*****/

void gpsBufferClass::Add(BYTE data)
{
    static BYTE lastChar(data); // Holds last for <cr> <lf> detection
    static Boolean lfFlag = FALSE; // True when message end is detected

    if (lfFlag && (data == '@')) { // Is a new message starting?
        last = current; // Set last to buffer with newest message.
        inc(current); // Set current to the next buffer
        // Set putPlace to the beginning of the next buffer.
        putPlace = &(block[current][0]);
        lfFlag = FALSE; // reset for end of next message.
    }

    *putPlace++ = data; // Write character into the buffer.

    // Has the end of a message been received?
    if ((lastChar == CARR_RETURN) && (data == LINE_FEED)) {
```

```

        lfFlag = TRUE;
    }
    lastChar = data;          //Save last character for <cr> <lf> detection
}

/*****
PROGRAM:      Get
AUTHOR:      Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:     Checks to see if a new message has arrived, copies it
into the input argument data and returns a flag to indicate whether
a new message was received
RETURNS:     TRUE, if a new valid position has been received.
             FALSE, otherwise
CALLED BY:   navPosit (nav.cpp), initializeNavigator (nav.cpp)
CALLS:      gpsBufferClass::hasData
*****/

Boolean gpsBufferClass::Get(GPSdata data)
{
    if (hasData( )) {          // Has a new valid message been received.
        // Copy the message out of the buffer.
        memcpy (data, block + last, GPSBLOCKSIZE);
        last = current;        // Indicate that this message has been read.
        return TRUE;
    }
    else {
        return FALSE;
    }
}

/*****
PROGRAM:      hasData
AUTHOR:      Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:     Determines whether a new message has been received and
checks to see if it has a valid header.
RETURNS:     TRUE, if a new valid message has been received.
CALLED BY:   gpsBufferClass::Get (buffer.cpp)
CALLS:      validHeader (buffer.cpp)
*****/

Boolean gpsBufferClass::hasData( )
{
    // Has a new message with a valid header been received
    if (last != current) {
        if (validHeader(block[last])) {
            return TRUE;
        }
        else {
            return FALSE;
        }
    }
    return FALSE;
}

```

```

/*****
PROGRAM:    validHeader
AUTHOR:     Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Checks to see if a message has the proper header for a
Motorola position message. (@@Ea)
RETURNS:     TRUE, if the header is valid. FALSE, otherwise.
CALLED BY:   gpsBufferClass::hasData (buffer.cpp)
CALLS:       none.
*****/

Boolean gpsBufferClass::validHeader(GPSdata dataPtr)
{
    if ((dataPtr[0] == '@') && (dataPtr[1] == '@') &&
        (dataPtr[2] == 'E') && (dataPtr[3] == 'a')) {
        ;
        return TRUE;
    }
    else {
        return FALSE;
    }
}
// end of file gpsbuff.cpp

```

F. COMPBUFF.H

```
#ifndef __COMPBUFF_H
#define __COMPBUFF_H

#include "toetypes.h"
#include "globals.h"
#include "buffer.h"

#define COMPBLOCKS      8
#define LINE_FEED      10
#define CARR_RETURN     13
#define g               103
#define o               111

/*****
  Class buffers COMPASS messages received via serial port
  communications. Uses a multiple buffer system in which each buffer is
  capable of holding a single message. Buffers are filled and processed
  sequentially in a round robin fashion. Messages are checked for
  validity only upon attempted reads from the buffer.
*****/

class compBufferClass : public bufferClass {

public:

    compBufferClass(BYTE compBlocks = COMPBLOCKS);

    ~compBufferClass() {delete [] block;}

    Boolean  hasData();                // a complete structure is ready
    Boolean  Get(BYTE&) {return FALSE;} // satisfy inheritance
requirements
    Boolean  Get(compData);            // get a complete structure filled in
    void     Add(BYTE ch);             // build the structure byte by byte

protected:                          // for inheritance

    Boolean  validHeader(compData);    // check a block for valid header
    compData *block;                 // points to array of compass msgs
    WORD     current, last;           // current and last comp block in use

    BYTE     *putPlace;               // for the next character received
};

#endif
```

G. COMPBUFF.CPP

```
#include <iostream.h>
#include <stdio.h>

#include "compbuff.h"

/*****
PROGRAM:   compBuffer (Constructor)
AUTHOR:    Eric Bachmann, Randy Walker
DATE:      28 April 1996
FUNCTION:   Allocates message buffers, indicates that no data has
been received by equalizing current and last and sets the position
into which initial character will be read.
RETURNS:    nothing.
CALLED BY:  compassClass (compass.h)
CALLS:      none.
*****/

compBufferClass::compBufferClass(BYTE compBlocks): current(0),
last(0), bufferClass(compBlocks) // Call to base class constructor
{
    cerr << "compBuffer constructor called" << endl;
    block = new compData[compBlocks]; // Create array of message
buffers
    putPlace = &(block[current][0]); // Set position for first char

    cerr << "compBuffer constructed." << endl;
}

/*****
PROGRAM:   compBuffer::Add
AUTHOR:    Eric Bachmann, Randy Walker
DATE:      28 April 1996
FUNCTION:   Interrupt driven routine which writes incoming characters
into the compass message buffers
RETURNS:    nothing.
CALLED BY:  interrupt driven by compassPort
CALLS:      none.
*****/

void compBufferClass::Add(BYTE data){

    static Boolean lfFlag = FALSE; //True, if message end detected
    static int messageCount(0); // Counts characters in current message

    if (lfFlag && (data == '$')) { // Is a new message starting?

        last = current; // Set last to buffer with newest message.
        inc(current); // Set current to the next buffer

        // Set putPlace to the beginning of the next buffer.
        putPlace = &(block[current][0]);
        lfFlag = FALSE; // reset for end of next message.
    }

    *putPlace++ = data; // Write character into the buffer.
}
```

```

    messageCount++;

    //Has the end of a message been received (<cr><lf>)?
    if (data == LINE_FEED) {
        lfFlag = TRUE;
    }
}

/*****
PROGRAM:    compBuffer::Get
AUTHOR:     Eric Bachmann, Randy Walker
DATE:       28 April 1996
FUNCTION:    Checks to see if a new message has arrived, copies it
into the input argument data and returns a flag to indicate whether
a new message was received.
RETURNS:    TRUE, if a new valid position has been received. FALSE,
otherwise
CALLED BY:   compass.cpp
CALLS:       compBuffer::hasData
*****/

Boolean compBufferClass::Get(compData data)
{
    if (hasData( )) {        // Has a new valid message been received.
        // Copy the message out of the buffer.
        memcpy (data, block + last, COMPSIZE);
        last = current;      // Indicate that this message has been read.
        return TRUE;
    }
    else {
        return FALSE;
    }
}

/*****
PROGRAM:    compBuffer::hasData
AUTHOR:     Eric Bachmann, Randy Walker
DATE:       28 April 1996
FUNCTION:    Determines whether a new message has been received and
Checks to see if it has a valid header.
RETURNS:    TRUE, if a new valid message has been received.
CALLED BY:   compBuffer::Get
CALLS:       validHeader (compBuffer.cpp)
*****/

Boolean compBufferClass::hasData()
{
    if ((last != current) && (validHeader(block[last]))) {
        return TRUE;
    }
    else {
        return FALSE;
    }
}

```

```

/*****
PROGRAM:      validHeader
AUTHOR:       Eric Bachmann, Dave Gay
DATE:        11 July 1995
FUNCTION:     Checks to see if a message has the proper header for a
compass message. ($C)
RETURNS:      TRUE, if the header is valid. FALSE, otherwise.
CALLED BY:    compBuffer::hasData
CALLS:        none.
*****/

Boolean compBufferClass::validHeader(compData dataPtr)
{
    if ((dataPtr[0] == '$') && (dataPtr[1] == 'C')) {
        return TRUE;
    }
    else {
        return FALSE;
    }
}
//end of file compbuff.cpp

```

H. CRBBUFF.H

```
#ifndef _CRBBUFF_H
#define _CRBBUFF_H

#include "globals.h"
#include "toetypes.h"
#include "buffer.h"

#define CRBBLOCKS      10
#define LINE_FEED      10
#define CARR_RETURN    13

/*****
   Class buffers Crossbow messages via serial port communications.
   Uses a multiple buffer system in which each buffer is capable of
   holding a single message. Buffers are filled and processed sequentially
   in a round robin fashion. Messages are checked for validity only upon
   attempted reads from the buffer.
*****/

class crbBufferClass : public bufferClass {

public:

    crbBufferClass(BYTE CRBblocks = CRBBLOCKS);
    ~crbBufferClass() { delete [] block; }

    Boolean  hasData();           // a complete structure is ready
    Boolean  Get(BYTE&) { return FALSE; }
    Boolean  Get(CRBdata);        // fill in a complete structure
    void     Add(BYTE ch);        // build the structure byte by byte

protected:

    Boolean  validHeader(CRBdata); // check a block for valid header
    CRBdata *block;               // hold the buffered Crossbow data
    WORD     current, last;       // current and last Crossbow block in use
    BYTE     *putPlace;          // for the next character received
};

#endif
```

I. CRBBUFF.CPP

```
#include <iostream.h>
#include <stdio.h>

#include "crbbuff.h"

/*****
PROGRAM:   crbBuffer (Constructor)
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Allocates message buffers, indicate that no data has been
received by equalizing current and last and set position into which
initial character will be read.
RETURNS:    nothing.
CALLED BY:  none
CALLS:      none.
*****/

crbBufferClass::crbBufferClass(BYTE CRBblocks) : current(0), last(0),
bufferClass(CRBblocks) // Call to base class constructor
{
    cerr << "constructing crossbow buffer" << endl;
    block = new CRBdata[CRBblocks]; // Create an array of CRBdata elements
    putPlace = &(block[current][0]) // Set the place for the first char
}

/*****
PROGRAM:   Add
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Interrupt driven routine which writes incoming characters
into the crossbow message buffers.
RETURNS:    nothing.
CALLED BY:  interrupt driven by bufferedSerialPort
CALLS:      none.
*****/

void crbBufferClass::Add(BYTE data)
{
    static short byteCount(22);
    byteCount++;

    if (data == 0xFF && (byteCount > 22)) {

        last = current;          // Set last to buffer with newest message.
        inc(current);            // Set current to the next buffer
        byteCount=1;
        // Set putPlace to the beginning of the next buffer.
        putPlace = &(block[current][0]);
    } //end if

    *putPlace++ = data;          // Write character into the buffer.
}
```

```

/*****
PROGRAM:    Get
AUTHOR:     Kad5ir Akyol, Eric Bachmann
DATE:       03 November 1998
FUNCTION:    Checks to see if a new message has arrived, copies it
into the input argument data and returns a flag to indicate whether a
new message was received      RETURNS:   TRUE, if a new valid
position has been received. FALSE, otherwise
CALLED BY:  crb.cpp
CALLS:      crbBufferClass::hasData
*****/

```

```

Boolean crbBufferClass::Get(CRBdata data)

```

```

{
    if (hasData()) {          // Has a new valid message been received.
        memcpy (data, block + last, CRBBLOCKSIZE);
        last = current;      // Indicate that this message has been read.
        return TRUE;
    }
    else {
        return FALSE;
    }
}

```

```

/*****
PROGRAM:    hasData
AUTHOR:     Kadir Akyol, Eric Bachmann
DATE:       03 November 1998
FUNCTION:    Determines whether a new message has been received and
Checks to see if it has a valid header.
RETURNS:    TRUE, if a new valid message has been received.
CALLED BY:  crbBufferClass::Get (buffer.cpp)
CALLS:      validHeader (crbbuffer.cpp)
*****/

```

```

Boolean crbBufferClass::hasData( )

```

```

{
    if (last != current) {
        if (validHeader(block[last])) {
            return TRUE;
        }
        else {
            return FALSE;
        }
    }
    return FALSE;
}

```

```

/*****
PROGRAM:    validHeader
AUTHOR:     Kadir Akyol, Eric Bachmann
DATE:       03 November 1998
FUNCTION:    Checks to see if a message has the proper header.
RETURNS:    TRUE, if the header is valid. FALSE, otherwise.
CALLED BY:  crbBufferClass::hasData
CALLS:      none.
*****/

```

```
Boolean crbBufferClass::validHeader(CRBdata dataPtr)
{
    if ((dataPtr[0] == 0xff)){
        return TRUE;
    }
    else {
        return FALSE;
    }
}
// end of file crbbuff.cpp
```

J. GPSPORT.H

```
#ifndef _GPSPORT_H
#define _GPSPORT_H

#include <dos.h>
#include <stdio.h>
#include "toetypes.h"
#include "globals.h"
#include "serial.h"
#include "gpsbuff.h"

// this is the type for a standard interrupt handler
typedef void interrupt (IntHandlerType)(...);

// com handler to interface with processInterrupt
void interrupt COM1handler(...);

/*****
CLASS:   gpsPortClass
AUTHOR:  Rick Roberts
DATE:    28 January 1997
FUNCTION: Defines a buffered serial port which is interrupt driven
on receive, and buffers all incoming characters in the gps buffer
*****/

class gpsPortClass : public serialPortClass {

public:

    gpsPortClass(COMport portnum = COM1, BYTE irq = 4,
                  BaudRate speed = b9600,
                  ParityType parity = NOPARITY, BYTE wordlen = 8,
                  BYTE stopbits = 1, handShake hs = XON_XOFF);
    ~gpsPortClass();

    Boolean Get(GPSdata& data);      // buffered version
    void processInterrupt();         // buffers the incoming character

protected:

    gpsBufferClass messages;

    BYTE irqbit; // Value to allow enable PIC interrupts for COM port
    BYTE origirq; // keep the original 8259 mask register value
    BYTE comint;

    IntHandlerType *origcomint; // keep original vector for restoring

    // this allows the actual handler to access processInterrupt()
    friend IntHandlerType COM2handler;

};

extern gpsPortClass port1;

#endif
```

K. GPSPORT.CPP

```
#include <iostream.h>
#include <stdio.h>

#include "gpsPort.h"

/*****
PROGRAM:    gpsPortClass (Constructor)
AUTHOR:     Rick Roberts
DATE:       28 January 1997
FUNCTION:    Initializes the interrupts for the gps Serial Port.
             1) takes over the original COM interrupt
             2) sets the port bits, parity, and stop bit
             3) enables interrupts on the 8250 (async chip)
             4) enables the async interrupt on the 8259 PIC
*****/

gpsPortClass::gpsPortClass(COMport portnum, BYTE irq, BaudRate baud,
                           ParityType parity, BYTE wordlen,
                           BYTE stopbits, handShake hs) :
    serialPortClass(portnum, baud, parity, wordlen,
                    stopbits, hs), irqbit(irq), comint(irqbit+8)
{
    cerr << "gpsPort constructor called" << endl;

    if (ShakeType == RTS_CTS) { // turn it off first, because it was
        enabled
            setDTRoff();          // in the base class
            setRTSoff();
        }

    origcomint = getvect(comint);    // remember the original vector

    setvect(comint,COM1handler);     // point to the new handler

    setportbit(MCR,3);               // turn OUT2 on
    disable();                       // disable all interrupts - critical section
    setportbit(IER,rx_rdy);          // enable ints on receive only
    origirq = inportb(IRQPORT);      // remember how it was
    clrportbit(IRQPORT,irqbit);      // enable COM ints

    if (ShakeType == RTS_CTS) {
        setDTRon();
        setRTSon();
    }
    enable();

    EOI;
    cerr << "exiting gpsPort constructor" << endl;
}
```

```

/*****
PROGRAM:   ~gpsPortClass
AUTHOR:    Rick Roberts, Frank Kelbe, Eric Bachmann, Dave Gay
DATE:      28 January 1997
FUNCTION:   Resets the interrupts.
           1) disables the 8250 (async chip)
           2) disables the interrupt chip for async int
           3) resets the 8259 PIC
*****/

gpsPortClass::~gpsPortClass()
{
    setvect(comint,origcomint);    // set the interrupt vector back
    outportb(IER,0);               // disable further UART interrupts
    outportb(MCR,0);               // turn everything off
    outportb(IRQPRT,origirq);
    EOI;
}

/*****
PROGRAM:   Get
AUTHOR:    Frank Kelbe, Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Calls Get based on buffer type
*****/

Boolean gpsPortClass::Get(GPSdata& data)
{
    return messages.Get(data);
}

/*****
PROGRAM:   COM1handler
AUTHOR:    Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:      11 July 1995, last modified January 1997
FUNCTION:   Specific interrupt handler which maps each interrupt to
           the proper ISR.
*****/

void interrupt COM1handler(...)
{
    port1.processInterrupt();
    EOI;
}

/*****
PROGRAM:   processInterrupt
AUTHOR:    Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:      11 July 1995
FUNCTION:   Calls the ISR based upon buffer type
*****/

void gpsPortClass::processInterrupt()
{
    if (dataReady()) {            // make sure there's a char there
        BYTE data = inportb(RX);  // read character from 8250
        messages.Add(data);
    }
}

```

```
        if (ShakeType == RTS_CTS && messages.capacityUsed() >
ALMOST_FULL)
            setDTRoff();
    }
}
// end of file gpsport.cpp
```

L. COMPPORT.H

```
#ifndef _MCOMPORT_H
#define _MCOMPORT_H

#include <dos.h>
#include <stdio.h>

#include "toetypes.h"
#include "globals.h"
#include "serial.h"
#include "compbuff.h"

// this is the type for a standard interrupt handler
typedef void interrupt (IntHandlerType)(...);

// com handler to interface with processInterrupt
void interrupt COM2handler(...);

/*****
CLASS:   compassPortClass
AUTHOR:  Rick Roberts
DATE:    28 January 1997
FUNCTION: Defines a buffered serial port which is interrupt
          driven on receive, and buffers all incoming characters in the
          compass buffer
*****/

class compassPortClass : public serialPortClass {

    friend compassClass;

public:

    compassPortClass(COMport portnum = COM2, BYTE irq = 3,
                     BaudRate speed = b9600,
                     ParityType parity = NOPARITY, BYTE wordlen = 8,
                     BYTE stopbits = 1, handShake hs = NONE);

    ~compassPortClass();

    Boolean    Get(BYTE& data); // buffered version

    void processInterrupt();    // buffers the incoming character

private:

    compBufferClass headings;

    BYTE irqbit; // Value to allow enable PIC interrupts for COM port
    BYTE origirq; // keep the original 8259 mask register value
    BYTE comint;

    IntHandlerType *origcomint; // keep original vector for restoring

    // this allows the actual handler to access processInterrupt()
```

```
        friend IntHandlerType COM2handler;  
};  
  
extern compassPortClass port2;  
  
#endif
```

M. COMPPORT.CPP

```
#include <iostream.h>
#include "compport.h"

/*****
PROGRAM:   compassPortClass (Constructor)
AUTHOR:    Rick Roberts
DATE:      28 January 1997
FUNCTION:   Initializes the interrupts for the compass Serial Port.
            1) takes over the original COM interrupt
            2) sets the port bits, parity, and stop bit
            3) enables interrupts on the 8250 (async chip)
            4) enables the async interrupt on the 8259 PIC
*****/

compassPortClass::compassPortClass(COMport portnum, BYTE irq,
                                     BaudRate baud, ParityType parity, BYTE wordlen,
                                     BYTE stopbits, handShake hs) :
    serialPortClass(portnum, baud, parity, wordlen,
                    stopbits, hs)
{
    cerr << "compassPort constructor called" << endl;

    irqbit = irq;
    comint = irqbit + 8;

    if (ShakeType == RTS_CTS) { // turn it off first, because it was
enabled
        setDTRoff();           // in the base class
        setRTSoff();
    }

    origcomint = getvect(comint); // remember the original vector

    setvect(comint, COM2handler); // point to the new handler

    setportbit(MCR, 3);          // turn OUT2 on
    disable();                    // disable all interrupts - critical section
    setportbit(IER, rx_rdy);      // enable ints on receive only
    origirq = inportb(IRQPORT);    // remember how it was
    clrportbit(IRQPORT, irqbit);  // enable COM ints

    if (ShakeType == RTS_CTS) {
        setDTRon();
        setRTSon();
    }
    enable();

    EOI;
    cerr << "exiting compassPort constructor" << endl;
}
```

```

/*****
PROGRAM:    ~compassPort
AUTHOR:     Rick Roberts, Frank Kelbe, Eric Bachmann, Dave Gay
DATE:       28 January 1997
FUNCTION:    Resets the interrupts.
            1) disables the 8250 (async chip)
            2) disables the interrupt chip for async int
            3) resets the 8259 PIC
*****/

compassPortClass::~compassPortClass()
{
    setvect(comint,origcomint);    // set the interrupt vector back
    outportb(IER,0);               // disable further UART interrupts
    outportb(MCR,0);               // turn everything off
    outportb(IRQPRT,origirq);
    EOI;
}

/*****
PROGRAM:    Get
AUTHOR:     Frank Kelbe, Eric Bachmann, Dave Gay
DATE:       11 July 1995
FUNCTION:    Calls Get based on buffer type
*****/

Boolean compassPortClass::Get(BYTE& data)
{
    return headings.Get(data);
}

/*****
PROGRAM:    COM2handler
AUTHOR:     Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995, last modified January 1997
FUNCTION:    Specific interrupt handler which maps each interrupt to
            the proper ISR.
*****/

void interrupt COM2handler(...)
{
    port2.processInterrupt();
    EOI;
}

/*****
PROGRAM:    processInterrupt
AUTHOR:     Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts
DATE:       11 July 1995
FUNCTION:    Calls the ISR based upon buffer type
*****/

void compassPortClass::processInterrupt()
{
    if (dataReady()) {
        BYTE data = inportb(RX);    // make sure there's a char there
        headings.Add(data);         // read character from 8250
    }
}

```

```
        if (ShakeType == RTS_CTS && headings.capacityUsed() >
ALMOST_FULL)
            setDTRoff();
    }
}
// end of file compport.cpp
```

N. CRBPORT.H

```
#ifndef _CRBPORT_H
#define _CRBPORT_H

#include <dos.h>
#include <stdio.h>
#include "toetypes.h"
#include "globals.h"
#include "serial.h"
#include "crbbuff.h"

// this is the type for a standard interrupt handler
typedef void interrupt (IntHandlerType)(...);

// com handler to interface with processInterrupt
void interrupt COM3handler(...);

/*****
CLASS:   crbPortClass
AUTHOR:  Kadir Akyol, Erich Bachmann
DATE:    03 November 1998
FUNCTION: Defines a buffered serial port which is interrupt
driven on receive, and buffers all incoming characters in the
gps buffer
*****/

class crbPortClass : public serialPortClass {

public:

    crbPortClass(COMport portnum = COM3, BYTE irq = 5,
                  BaudRate speed = b38400,
                  ParityType parity = NOPARITY, BYTE wordlen = 8,
                  BYTE stopbits = 1, handShake hs = NONE);
    ~crbPortClass();

    Boolean Get(CRBdata& data);      // buffered version
    void processInterrupt();         // buffers the incoming character

protected:

    crbBufferClass messages;

    BYTE irqbit; // Value to allow enable PIC interrupts for COM port
    BYTE origirq; // keep the original 8259 mask register value
    BYTE comint;

    IntHandlerType *origcomint; // keep original vector for restoring

    // this allows the actual handler to access processInterrupt()
    friend IntHandlerType COM2handler;
};

extern crbPortClass port3;

#endif
```

O. CRBPORT.CPP

```
#include <iostream.h>
#include <stdio.h>
#include "crbPort.h"

/*****
PROGRAM:   crbPortClass (Constructor)
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Initializes the interrupts for the gps Serial Port.
            1) takes over the original COM interrupt
            2) sets the port bits, parity, and stop bit
            3) enables interrupts on the 8250 (async chip)
            4) enables the async interrupt on the 8259 PIC
*****/

crbPortClass::crbPortClass(COMport portnum, BYTE irq, BaudRate baud,
                           ParityType parity, BYTE wordlen,
                           BYTE stopbits, handShake hs) :
    serialPortClass(portnum, baud, parity, wordlen,
                    stopbits, hs), irqbit(irq), comint(irqbit+8)
{
    cerr << "crbPort constructor called" << endl;

    if (ShakeType == RTS_CTS) { // turn it off first, because it was
        enabled
            setDTRoff(); // in the base class
            setRTSoff();
        }

    origcomint = getvect(comint); // remember the original vector

    setvect(comint, COM3handler); // point to the new handler

    setportbit(MCR, 3); // turn OUT2 on
    disable(); // disable all interrupts - critical section
    setportbit(IER, rx_rdy); // enable ints on receive only
    origirq = inportb(IRQPORT); // remember how it was
    clrportbit(IRQPORT, irqbit); // enable COM ints

    if (ShakeType == RTS_CTS) {
        setDTRon();
        setRTSon();
    }

    enable();

    EOI;
    cerr << "exiting crbPort constructor" << endl;
}
```

```

/*****
PROGRAM:   ~crbPortClass
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Resets the interrupts.
            1) disables the 8250 (async chip)
            2) disables the interrupt chip for async int
            3) resets the 8259 PIC
*****/

crbPortClass::~crbPortClass()
{
    setvect(comint,origcomint);    // set the interrupt vector back
    outportb(IER,0);               // disable further UART interrupts
    outportb(MCR,0);               // turn everything off
    outportb(IRQPRT,origirq);
    EOI;
}

/*****
PROGRAM:   Get
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Calls Get based on buffer type
*****/

Boolean crbPortClass::Get(CRBdata& data)
{
    return messages.Get(data);
}

/*****
PROGRAM:   COM1handler
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      11 July 1995, last modified November 1998
FUNCTION:   Specific interrupt handler which maps each interrupt to the
            proper ISR.
*****/

void interrupt COM3handler(...)
{
    port3.processInterrupt();
    EOI;
}

/*****
PROGRAM:   processInterrupt
AUTHOR:    Kadir Akyol, Eric Bachmann
DATE:      03 November 1998
FUNCTION:   Calls the ISR based upon buffer type
*****/

void crbPortClass::processInterrupt()
{
    if (dataReady()) {            // make sure there's a char there
        BYTE data = inportb(RX);  // read character from 8250
        messages.Add(data);
    }
}

```

```
        if (ShakeType == RTS_CTS && messages.capacityUsed() >
ALMOST_FULL)
            setDTRoff();
    }
}
// end of file crbport.cpp
```

P. SERIAL.H

```
#ifndef _SERIAL_H
#define _SERIAL_H

#include <dos.h>
#include <stdio.h>
#include "globals.h"

#define ALMOST_FULL 80 // % full to turn off DTR (user defines)

// leave the following alone - hardware specific
enum COMport {COM1=1, COM2, COM3, COM4};
enum BaudRate {b300, b1200, b2400, b4800, b9600, b38400};
enum ParityType {ERROR=-1, NOPARITY, ODD, EVEN};
enum handShake {NONE, RTS_CTS, XON_XOFF};
enum Shake {off, on};
enum interruptType {rx_rdy, tx_rdy, line_stat, modem_stat};

#define BIOSMEMSEG 0x40
#define DLAB 0x80
#define IRQPORT 0x21
#define EOI outportb(0x20, 0x20)

#define COM1base MEMW(BIOSMEMSEG, 0)
#define COM2base MEMW(BIOSMEMSEG, 2)
#define COM3base MEMW(BIOSMEMSEG, 4)

#define TX (portBase)
#define RX (portBase)
#define IER (portBase+1)
#define IIR (portBase+2)
#define LCR (portBase+3)
#define MCR (portBase+4)
#define LSR (portBase+5)
#define MSR (portBase+6)
#define LO_LATCH (portBase)
#define HI_LATCH (portBase+1)

/*****
CLASS: serialPortClass
AUTHOR: Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts, Kadir Akyol
DATE: 11 July 1995, last modified March 1999
FUNCTION: Parent class, defines a simple serial port.
*****/

class serialPortClass {

public:

    serialPortClass(COMport port, BaudRate baud, ParityType parity,
        BYTE wordlen, BYTE stopbits, handShake hs);
    ~serialPortClass() {}

    Boolean Send(BYTE data);
    Boolean Get(BYTE& data);
};
```

```

inline Boolean dataReady();
Boolean statusChanged()
{ return Boolean((ifportbit(MSR,0) || ifportbit(MSR,1))); }

// the rest are only if handshake is specified as RTS_CTS
Boolean    isCTSon()           { return ifportbit(MSR,4); }
Boolean    isDSRon()           { return ifportbit(MSR,5); }

void       setDTRon()           { setportbit(MCR,0); }
void       setDTRoff()          { clrportbit(MCR,0); }
void       toggledTR();
void       setRTSon()           { setportbit(MCR,1); }
void       setRTSoff()          { clrportbit(MCR,1); }
void       toggleRTS();

protected:

WORD        portBase;
handShake   ShakeType;
Shake       DTRstate, RTSstate;

inline Boolean    ifportbit(WORD, BYTE);
inline void       toggle(Shake&);

};

#endif

```

Q. SERIAL.CPP

```
#include <iostream.h>
#include <stdio.h>
#include "serial.h"

/*****
PROGRAM: serialPortClass (Constructor)
AUTHOR:  Frank Kelbe, Eric Bachmann, Dave Gay, Rick Roberts, Kadir Akyol
DATE:    11 July 1995, last modified March 1999
FUNCTION: Initializes one of the Serial Ports.
    1) Determines the base I/O port address for the given COM port
    2) Sets the 8259 IRQ mask value
    3) Initializes the port parameters - baud, parity, etc.
    4) Calls the routine to initialize interrupt handling
    5) Enables DTR and RTS, indicating ready to go
*****/

serialPortClass::serialPortClass(COMport port, BaudRate speed,
                                   ParityType parity, BYTE wordlen,
                                   BYTE stopbits, handShake hs) :
                                   DTRstate(off), RTSstate(off), ShakeType(hs)
{
    cerr << "serialPort constructor called" << endl;
    delay(500);

    switch (port) { // initialize appropriate port base
        case COM1: portBase = COM1base;
            break;

        case COM2: portBase = COM2base;
            break;

        case COM3: portBase = COM3base;
            break;
    } // switch

    const WORD    bauddiv[] = {0x180, 0x60, 0x30, 0x18, 0xC, 0x03};

    // Change 1
    outportb(IER,0); // disable UART interrupts
    (void)inportb(LSR);
    (void)inportb(MSR);
    (void)inportb(IIR);
    (void)inportb(RX);

    outportb(LCR,DLAB); // set DLAB so can set baud rate (read only port)
    outportb(LO_LATCH,bauddiv[speed] & 0xFF);
    outportb(HI_LATCH,(bauddiv[speed] & 0xFF00) >> 8);
    setportbit(MCR,3); // turn OUT2 on

    BYTE opt = 0;
    if (parity != NOPARITY) {
        setbit(opt,3); // enable parity
        if (parity == EVEN) // set even parity bit. if odd, leave bit 0
            setbit(opt,4);
    }
}
```

```

// now set the word length. len of 5 sets both bits 0 and 1 to
// 0, 6 sets to 01, 7 to 10 and 8 to 11
opt |= wordlen-5;
opt |= --stopbits << 2;
outportb(LCR,opt);

if (ShakeType == RTS_CTS) {
    setDTRon();
    setRTSon();
}
cerr << "serialPort constructed" << endl;
}

/*****
PROGRAM:    Get
AUTHOR:    Frank Kelbe, Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Gets a byte from the port. Returns true if there's one
there, and fills in the byte parameter. If there's no character,
the parameter is left alone, and false is returned.
*****/

Boolean serialPortClass::Get(BYTE& data)
{
    if (dataReady()) {                // make sure there's a char there
        data = inportb(RX);           // read character from 8250
        return TRUE;
    }
    else
        return FALSE;
}

/*****
PROGRAM:    Send
AUTHOR:    Frank Kelbe, Eric Bachmann, Dave Gay
DATE:      11 July 1995
FUNCTION:   Outputs a single character to the port. Returns Boolean
status indicating whether successful
*****/

Boolean serialPortClass::Send(BYTE data)
{
    while (!(ifportbit(LSR,5))) {};    // wait until THR ready

    switch (ShakeType) {
        case NONE:
            outportb(TX,data);
            return TRUE;

        case RTS_CTS:
            if (isCTSon() && isDSRon()) {
                outportb(TX,data);
                return TRUE;
            }
            else {
                return FALSE;
            }
    }
}

```

```

        default:
            break;
    }

    return FALSE;
}

/*****
PROGRAM:  dataReady
AUTHOR:   Frank Kelbe, Eric Bachmann, Dave Gay
DATE:     11 July 1995
FUNCTION:  Checks port to see if a character has arrived.
*****/

inline Boolean serialPortClass::dataReady()
{
    /*    Un-commenting this code increases transmission errors, but this
        code is useful for troubleshooting, so is retained if needed
        if (ifportbit(LSR,1)) {
            cerr <<"\nOverrun Error\n";
        }
        if (ifportbit(LSR,2)) {
            cerr <<"\nParity Error\n";
        }
        if (ifportbit(LSR,3)) {
            cerr <<"\nFraming Error\n";
        }
    */

    return ifportbit(LSR,0);
}

/*****
PROGRAM:  ifportbit
AUTHOR:   Frank Kelbe, Eric Bachmann, Dave Gay
DATE:     11 July 1995
FUNCTION:  Checks for byte on inportb register
*****/

inline Boolean serialPortClass::ifportbit(WORD reg, BYTE bit)
{
    BYTE on = inportb(reg);
    on &= set(bit);
    return Boolean(on == set(bit));
}

/*****
PROGRAM:  toggledTR
AUTHOR:   Frank Kelbe, Eric Bachmann, Dave Gay
DATE:     11 July 1995
FUNCTION:  toggles Data Transmit Ready if RTS_CTS is off
*****/

void serialPortClass::toggledTR()
{
    if (ShakeType != RTS_CTS)
        return;
}

```

```

    if (DTRstate == off)
        setDTRon();
    else
        setDTRoff();
    toggle(DTRstate);
}

/*****
PROGRAM:  toggleRTS
AUTHOR:   Frank Kelbe, Eric Bachmann, Dave Gay
DATE:     11 July 1995
FUNCTION:  toggle Ready to Send (RTS) if RTS_CTS is on.
*****/

void serialPortClass::toggleRTS()
{
    if (ShakeType != RTS_CTS)
        return;
    if (RTSstate == off)
        setRTSon();
    else
        setRTSoff();
    toggle(RTSstate);
}

/*****
PROGRAM:  toggle
AUTHOR:   Frank Kelbe, Eric Bachmann, Dave Gay
DATE:     11 July 1995
FUNCTION:  toggles value of the input variable
*****/

inline void serialPortClass::toggle(Shake& h)
{
    if (h == off)
        h = on;
    else
        h = off;
}

// end of file serial.cpp

```


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