Development of a Low-Cost GPS-Based Time-Space-Positioning Information(TSPI) System

Benge D. Scott
Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake

BIOGRAPHY

Benge Scott received his B.S. in Engineering from Walla Walla College in 1989. He came to China Lake in 1989 and has been involved in the design and analysis of advanced digital systems. Currently he is a GPS Systems Engineer for the Navigation and Data Links Section at NAWCWPNS, China Lake.

ABSTRACT

The Navigation and Data Link Section of NAWCWPNS China Lake was tasked to develop a low cost Time-Space-Position-Information (TSPI) system for airborne vehicles based on GPS technology. The portable system developed provides vehicle positioning information in geographic areas not supported by instrumented ranges while maintaining compatibility with existing telemetry range assets. The system reports TSPI data via an RF down link in a standard PCM telemetry frame format. An onboard data logger is provided for telemetry backup while an interface for sampling analog input signals and incorporating the data into the telemetered data is also provided. Development cost was minimized by utilizing off-the-shelf industrial components modified slightly to tolerate the environmental conditions. This system provides the Navy with an inexpensive but highly adaptable and capable TSPI system.

INTRODUCTION

Operational and budgetary constraints of the Navy's test community is the driving force behind the need for an off-range, time-space-position information (TSPI) system. The system developed is one which provides modest TSPI accuracy with a rapid deployment capability while remaining cost effective for both development and production. To meet these requirements the GPS Reporting Information Positioning System (GRIPS) was developed by the Navigation and Data Link Section at the Naval Air Warfare Center, Weapons Division, China Lake.

SYSTEM OVERVIEW

GRIPS is a portable vehicle tracking system consisting of a portable base station and a remote rover unit. The base station receives position data broadcast from the rover unit and provides display and recording capability to ground personnel. The base station is located at a suitable observation point for the desired mission while the rover unit is installed into the particular vehicle being monitored The rover unit broadcasts its position and velocity information to the base station where it is displayed and recorded for post-mission analysis. Because of the data link's L-band frequency employed, the base station requires a line-of-sight to the roving vehicle to maintain telemetry lock. Currently, only one rover unit is capable of being tracked at any given time.

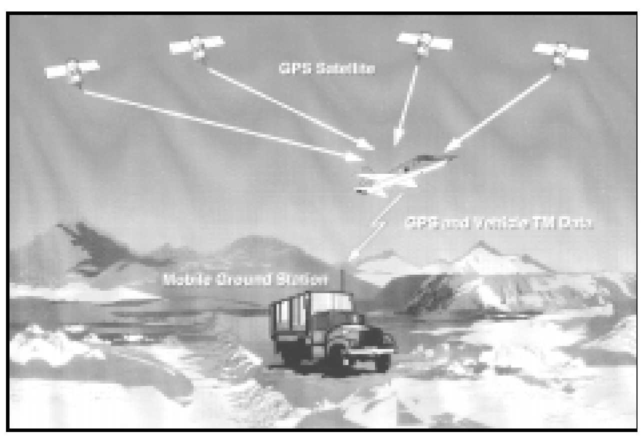

Figure1. GRIPS System

By utilizing a standard pulse-code-modulation (PCM) telemetry-frame format, system compatibility with established range assets is maintained. The frame definition utilizes a data rate of 125 Kbits/second and frame size of 512, 16-bit words. This provides a 15.3 Hz frame rate for the system.

Both the base station and rover unit were designed to maximize the use of industrial commercial-off-the-shelf (COTS) components. Though using COTS items, it was still necessary to maintain the ability to operate in a typical military test-flight environment.

The rover uses an embedded GPS receiver to determine its current position. It also is able to monitor analog signals from the host vehicle such as barometric altitude, pitch and roll attitudes, temperature, and bus voltages. As well as transmitting this data to the base station, the rover is able to record the data being transmitted. This capability allows for system integrity in the event of TM data drop outs during the mission.

SYSTEM DESCRIPTION

Portable Base Station

The base station's function is to receive, display and record the telemetry data from the rover unit. Figure 2 is a block diagram of the base station's design.

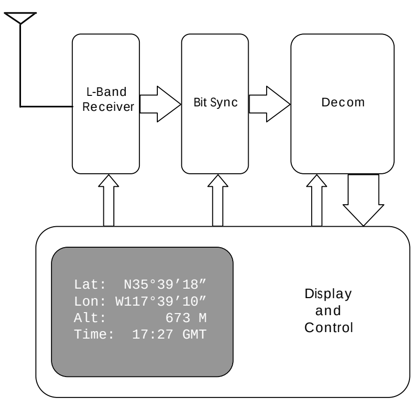

Figure 2. Base Station Block Diagram

FUNCTIONAL DESIGN Telemetry data is received by an L-band receiver which removes the RF carrier. The resulting base-band data stream is then passed onto the Bit Sync. At this point the data stream is in an IRIG standard, randomized non-return-to-zero (RNRZ) format. The Bit Sync generates a data clock which is phase-locked to the incoming data stream. The data is then converted into a non-return-to-zero (NRZ) format and passed onto the Decom. The Decom processes this NRZ data stream to locate the frame boundaries and finally reassemble the telemetry data into an organized data structure in the computer's memory.

The PCM telemetry frame is of a rate, size, and data format typical to that encountered on instrumented ranges. This capability allows for the rover unit to be utilized on existing ranges without special configuration changes to the range equipment. This compatibility also permits telemetry data reduction to be performed by existing range assets.

The data rate of the data link is 125 Kbits/second. A frame is defined as 512 16-bit words with a 32-bit frame sync word beginning each frame. With this data rate and frame definition, a frame rate of approximately 15.3 Hz is attained.

HARDWARE IMPLEMENTATION The base-station hardware is a ruggedized IBM compatible PC housed in a portable, 19-inch industrial, instrumentation rack. Two, COTS ISA bus boards are installed which perform the receiver and bit sync/decom functions. These boards were procured from Berg Systems International (BSI). A SVGA monitor and pull-out keyboard are provided for the operator interface. System power is buffered through a conditioner.

Figure 3. GRIPS Portable Base Station

BASE STATION SOFTWARE The base-station interface and control software was also a COTS item and also provided by BSI. This software configures the receiver and bit sync/decom boards and provides a means for displaying the incoming telemetry data in real time. Recording and playback capabilities are also provided for later data analysis and archiving.

Rover Unit

The rover computes its current location, digitizes the analog inputs, records, formats, and down links this data to the base station. Functionally the rover can be divided into eight elements. Figure 4 is a block diagram of the rover design.

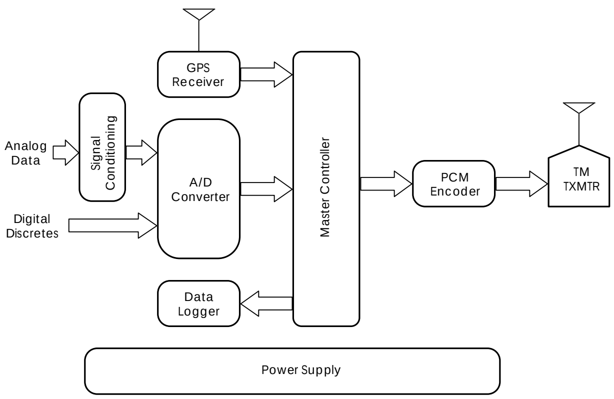

Figure 4. Rover Block Diagram

MASTER CONTROLLER The Master Controller is responsible for gathering the information from the GPS receiver and A/D converters. It formats this information and places the data into the output frame buffer. The Master Controller also outputs the data to the Encoder and Data Logger.

GPS RECEIVER The GPS Receiver computes the rover's position and provides time information for the system. Utilizing a Trimble C/A-code module, the GPS Receiver communicates with the Master Controller through a serial interface using the Trimble Serial Interface Protocol (TSIP).

A/D CONVERTER The analog signals available on the vehicle to be monitored are included in the telemetry frame via the Analog-to-Digital (A/D) Converter function. Two 16 bit A/D converters accommodate both unipolar (+) and bipolar (±) voltages. These converters are able to digitize a total of fifteen channels of analog inputs with seven channels dedicated to unipolar voltages and the remaining eight for bipolar voltages. An additional analog input is dedicated to handling a thermistor for temperature measurement

The A/D Converter also has 32 channels of digital discrete inputs for event monitoring. These inputs accept a TTL-compatible input voltage to indicate an on or off condition. Both the analog and digital discrete inputs are sampled every telemetry frame producing an input sample rate of 15.3 Hz.

SIGNAL CONDITIONING Some input voltages require scaling because their maximum range exceeds the input range of the A/D converters. Input scaling is accomplished by a precision voltage-divider network.

PCM ENCODER The Encoder incorporates a 2Kx8bit FIFO which allows the Master Controller to off-load two consecutive telemetry frames to the Encoder. The Encoder indicates to the Master Controller when only one frame of data remains in the FIFO. The Master Controller maintains complete control of the Encoder by monitoring the FIFO fill status. The Master Controller also has the ability to reinitialize the Encoder and reset the FIFO. A pre-modulation filter performs the last stage of data processing before the stream goes to the TM Transmitter.

DATA LOGGER The rover is capable of sustained data logging rates of 700 bytes/sec. With the current 10 Mbyte memory card the Data Logger is capable of mission durations of about four hours. To maximize data storage capability, data is only recorded when there is a new update to the data. Thus for the A/D inputs, data is logged every frame. For the GPS inputs, data is logged at a 1-Hz rate. Each time data is logged, a time tag based on GPS time is logged as well. This strategy allows for reconstruction of the mission but eliminates the recording of redundant data.

POWER SUPPLY The Power Supply converts the host vehicle's supply voltage of 28Vdc to a 5Vdc source required by the rover's internal electronics. It includes both input and output EMI filtering, thus protecting both the rover and the host vehicle from possible spurious voltage spikes.

TM TRANSMITTER This two-watt analog transmitter is powered separately from the rest of the rover's electronics. This allows the rover to initialize and acquire a GPS lock without transmitting data. A separate power feed is provided for the transmitter to implement this option.

Figure 5. GRIPS Rover Unit
(Scale in view is 6 inches)

HARDWARE IMPLEMENTATION The hardware used for the majority of the rover's electronics is based on the PC/104 embedded PC specification[1] for industrial applications. This specification defines a compact version of the IEEE P996[2] (PC and PC/AT) bus and is optimized for embedded applications. The form factor called out by the PC/104 specification reduces board size to 3.550 x 3.775 inches and eliminates the backplane by utilizing a self-stacking bus.

The Master Controller is implemented by an Intel 80486 compatible mother board utilizing a PC-DOS compatible operating system. A PCMCIA-II interface board accommodates the Data Logger function and is implemented with a PCMCIA ATA FLASH memory card. This device appears to the system as a DOS hard drive. Two A/D boards provide the analog input capability with the Trimble SVee-Six GPS receiver board at the top of the stack.

The COTS circuit boards were modified slightly to enhance their ability to withstand the anticipated vibration stresses. These modifications consisted primarily of spot bonding the socketed components and the larger components on each of the boards with epoxy. Conformal coating was also applied to the boards for enhanced environmental protection.

Of the six COTS boards utilized in the rover, the GPS receiver board required the most modification. In addition to spot bonding and conformal coating, the GPS RF-input connector was changed from an SMB to an SMA type connector and two mounting holes were drilled.

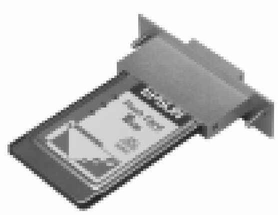

Figure 6. Data Logger Card - Rover Unit

Though most hardware utilized in the rover unit is COTS, the one exception is the Encoder board. The Encoder board not only incorporates the Encoder function but also includes the signal conditioning capability and the power supply.

Initially a COTS DC-DC converter was considered for the power supply but concerns over the EMI characteristics of available converters prompted the decision to design a custom power supply with input and output EMI filters. The resulting supply accepts input voltage ranges from 17 to 40 Vdc with a full load of 1.8 Amps. Efficiency at full load is 76%. Input ripple at rated load is 15 mV_{p-p} and output ripple is 8 mV_{p-p}. The power supply also maintains crowbar protection against output shorts.

ROVER SOFTWARE The software is written in C and is comprised of 2,300 lines of code. Its modular approach mimics the design of the hardware. The software's block diagram is depicted in Figure 7.

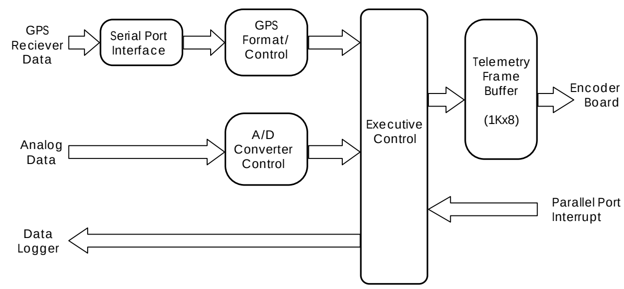

Figure 7. Rover Software block Diagram

When system power is supplied to the rover, it boots up into DOS and then automatically executes the system software. Due to operational constraints, the rover does not have a battery for GPS almanac retention so time-to-first-fix is dictated by the cold start capabilities of the SVee-Six GPS receiver. Typical observed acquisition times from a cold start have nominally occurred within 3 to 5 minutes from application of power.

To improve the acquisition times for the GPS set, a copy of the latest almanac is stored in EEPROM memory on the CPU motherboard which does not require a battery for data retention. On power up, the almanac is retrieved from this memory and loaded into the GPS set. For short power cycles, reacquisition times have been observed on the order of 3-30 seconds.

Also during the initialization phase, the rover prepares the Data Logger by creating an empty data log file. If a previous log file exists, the rover will append the new data to the end of the existing file. This prevents the loss of data during a mission in the event of a full system reset.

The rover implements both a Power-up Built-In-Test (BIT) and a Continuos BIT. If a failure is detected an indication is made in the telemetry frame. If possible, the rover will attempt to rectify the problem by reinitializing the failed sub-system. Periodic attempts continue to be made even if the first reinitialization attempt failed. To protect against total system lock-up, a watch-dog timer will perform a total system reset if it is allowed to time out in 2 seconds.

ROVER ENCLOSURE Packaging constraints proved challenging due to the limited volume available in the customer's vehicle. A maximum volume of 7x8x4 inches was available for the entire rover unit including transmitter and connector space. The packaging requirements were further challenged by the rugged environment in which the rover would be operated. Cooling was limited to convection since the instrumentation bay of the vehicle was entirely sealed with no forced-air cooling available. The rover unit also needed to sustain possible exposure to water in a spray or splash form.

The enclosure a welded aluminum assembly with mating flanges on top and bottom to attach the bottom and cover plates. The bottom plate doubles as a mounting flange for the rover and also serves as a base plate for the PC/104 electronics assembly inside the enclosure. The encoder board mounts to the inside aft wall of the enclosure. Fabricated from 0.25 inch aluminum, this aft wall also serves as the mount and heatsink for the transmitter which is located on the outside of the enclosure. The complete enclosure assembly is treated with a chemical conversion coating to resist corrosion. Each connector selected is unique in either size or configuration to help avoid possible mis-connects. Ease of manufacturing and assembly factored heavily in the design of the rover unit in an attempt to minimize future production costs.

Rover Environmental Testing

The rover was initially designed for an airborne application. Pre-flight environmental screening of the first flight-test article was performed to reduce the risk of mortality during the actual flight. The test's objectives were to validate the rover's ability to withstand a typical flight environment. The test plan required temperature cycling, mechanical shock, and vibration.

Temperature cycling not only tests the units ability to operate at the required temperature extreme but also evaluates the rover's ability to handle temperature shock. The rover was operated in an ambient temperature ranging from -20 °F to 140 °F with temperature gradients of 15°F± 5°F. Temperatures inside the enclosure were observed to range from 13°F to 164°F when the unit was subjected to the required ambient environment. The system was allowed to temperature stabilize such that the internal temperature gradients were below 0.06 °F/min.

Mechanical shock testing required a ±15 G, 11 millisecond terminal sawtooth shock in the major axis of the unit and a 0.02 G^2/Hz power spectral density (PSD) vibration profile from 20 - 2000 Hz in all three major axes.

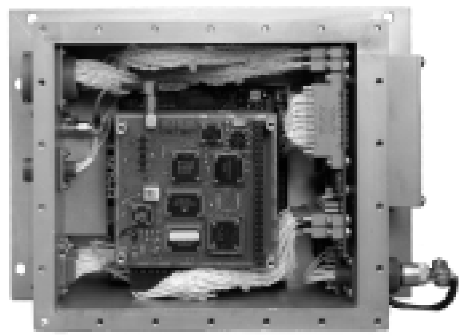

Figure 8. Top and Inside View of Rover Unit

The rover remained operational during each phase of the test and passed without failure. At this time the actual flight test has not been performed. The system has been tested using both ground vehicles and a helicopter to validate its operational performance. MTBF figures are yet to be determined.

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