Computing requirements for Ring Laser Gyro based INS-GPS System

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ABSTRACT

Ring laser gyro is state of art inertial optical gyroscope functioning on the principle of Sagnac effect. The performance of the RLG depends on the degree of stability of its control loop electronics and high precision signal processing capabilities including filtering and online error compensation. The RLG electronics is designed based on a DSP capable enough to take care of required computational load. The functional requirements for RLG include controlling the laser parameters like optical power, cavity path length, resonant mechanical bias up to a very high accuracy levels in closed loop characterized by high dynamic operational range. The signal processing applications like filtering and error compensation are required to be computed online within the time set by the navigation system. The output of the RLG is rate information superimposed with inertial errors like bias, misalignment and scale factor deviations. The navigation processor should acquire the three orthogonally mounted RLGs and Accelerometer data at faster rate and execute the error compensation, coning and sculling algorithms to extract the true rotational information. The navigation processor has to compute the pure and hybrid navigation functions in real time and execute the flight management functions like built-in self test, data posting to on-board computer system, data recovery in power failure condition, inter-processor communication, etc. To implement these computationally intensive functions, design of the navigation processor electronics has been realized using an ADSP floating point processor. This paper explains the computational architecture and selection criteria of processors for inertial sensors and navigation applications with the design and implementation details of sensor electronics for RLG and processor electronics for inertial navigation applications.

Keywords: RLG- Ring Laser Gyro; INS- Inertial Navigation system; GPS- Global Positioning system; MIPS- Million instructions per second; MFLOPS- Million floating operations per second

1. INTRODCUTION

A processor selection criteria depends on the performance on relevant tasks: speed, number of MIPS and MFLOPS available, numeric fidelity- fixed point vs floating point, data word size; execution time predictability, energy consumption, memory bandwidth, on-chip integration- coprocessors, memory, i/o interfaces; packing options- sizes, temperature ranges, ease of manufacturing; availability and reliability of supply; programming language complexity; development tools availability, etc.

The rate sensor Ring laser gyro has got more of controlling functions and digital filtering on various signals as described in the following sections. The processor should work at high clock speed for a high data sampling, should have built in multiply and accumulate module for implementing digital filtering and some on chip peripherals like I/O modules, memory, high speed serial link, PWM generator etc. ADSP-2186 processor is chosen for these functions of RLG. In RLG there is no floating point operation used, approximately 60 percent of the processor MIPS are used for control functions and computations.

The navigation processor module has got numeric intensive navigation algorithms such as sensor modeling, quaternion computation, formulation of dcm, kalman filtering and so on, which requires wide dynamic range, 64-bit floating point operations; on chip peripherals required are SRAM, DMA, high speed serial link, MAC for mathematical modeling, timer for real time clock generation, pipe lining, etc. the processor should also has to perform the general purpose flight management functions, data communication to flight computer. ADSP-21060 processor is chosen for the system. The MIPS and MFLOPS required for the computational load of navigation processor is approximately 30. The ADSP-21060 processor provides up to 40 MIPS and MFLOPS.

2. COMPUTATIONAL REQUIREMENTS OF RLG

2.1 Introduction to Ring Laser Gyro (RLG)

The Ring Laser Gyro is an inertial sensor that provides an output frequency proportional to the inertial angular rate about its sensitive axis. It is an optical gyro whose working principle is based on Sagnac effect.

This instrument is an essential requirement for navigation and control of a moving vehicle. It is required to determine the direction along which the vehicle is moving with respect to a reference set of coordinate frame. The property of gyroscope is basically defined by three parameters. Scale factor stability, the zero bias stability and the sensitivity to the environment (i.e. angular acceleration, linear acceleration & temperature). The above factors will determine the accuracy of the orientation of the vehicle, which can be measured and subsequently used for controlling and guiding the moving vehicle.

Table1. Performance Specification

Input Rate Range	±360deg/sec
Bias Stability	0.01deg/hr
Angular Random Walk	0.003 deg/√hr
Scale Factor Stability	10ppm

2.2 The Processor module in RLG implements the following functions

2.2.1 Sequential initiation of laser

2.2.2 Pseudorandom noise generation and digital PLL

2.2.3 Closed loop intensity control

2.2.4 Closed loop cavity path length control

2.2.5 On-line dither stripping by adaptive filter

2.2.6 On-line Temperature correction of gyro output

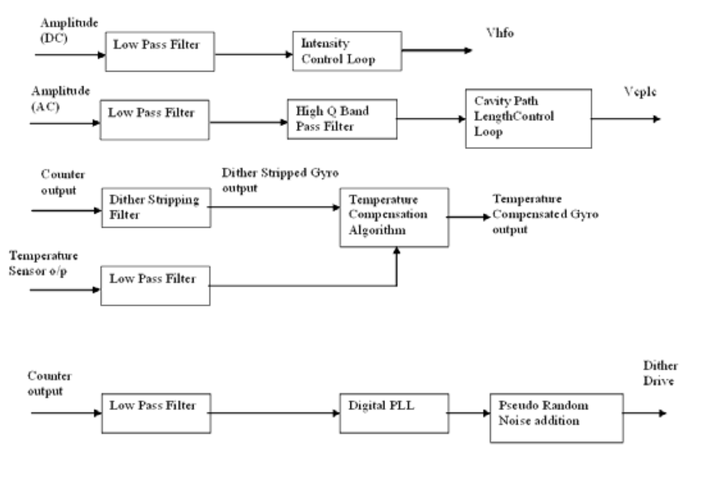


Fig1. Computational blocks of Ring Laser Gyro

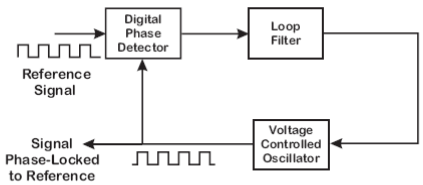
All these function are carried out using Analog Devices Digital Signal Processor ADSP-2186

2.2.1 Sequential initiation of laser

After power on, the processor has to generate a control signal for initiation of laser discharge. On the presence of optical signal, the processor stops giving the further commands. Otherwise after a delay it again generates another command. This is repeated four times and still if no optical signal is present, it generates an error code.

2.2.2 Closed loop digital PLL for dither

The PLL implemented in the DSP has got following functional block diagram.



As the resonance frequency keeps varying it develops a phase difference with input drive signal and this difference is used to correct the frequency change.

2.2.3 Pseudorandom noise generation

Linear congruence method is used to generate the pseudorandom noise. Input to this module is user programmable data like noise amplitude, noise frequency.

$$N=aS \bmod b + c.$$

a, b, c are chosen such that repeatability of this noise very low.

2.2.4 Closed loop intensity control

This module implements a set-point control algorithm to maintain the intensity of laser at its peak value. The DSP collects the sine amplitude data from ADC and filters out high frequency noises like quantization by implementing a fourth order low-pass filter. Then this data is compared with the set point and based on the error corresponding signal is generated and passed through an integrator. The integrator output is used for correcting the laser intensity.

2.2.5 Closed loop cavity path length control

This module implements a proportional integral (PI) control algorithm to maintain the laser cavity path length an integral multiple of laser wavelength through out the operating temperature of the Ring Laser Gyro. For this purpose the processor generates a modulating sinusoidal signal samples by following algorithm.

$$\mathrm{Sin}(x)= 3.140625x+0.02026367x2-5.325196x3+0.5446778x4+1.800293x6$$

The approximation is accurate for any value of x from 0 to +90 ^{O}C (i.e. the first quadrant). However because sin(-x) = -sin(x) and sin(180-x)=sin(x), the other quadrant values are inferred from 1st quadrant output.

The amplitude modulated feedback signal is taken from the ADC and following calculations are made on the data. The ADC output is passed through a fourth order low pass filter and then passed through a high-Q notch filter to extract the modulating signal. A digital phase detector is implemented whose output is proportional to the phase difference between the extracted signal and reference signal. This output is multiplied by the scale factor and integrated to generate the path length correction signal.

2.2.6 On line dither stripping

The composite count which is obtained by processing the two photo detector outputs is a digitized representation of the net angular displacement of the RLG, due to dither as well as the gross motion of the body to which the RLG is strapped.

Since the composite count is obtained by accumulation of the pulses over a sampling interval, there is no loss of dither or the external displacement information. However, when transformed to the frequency domain, the dither displacement signal and the signal representing the gross motion occupy significantly different portions of the frequency spectra. The dither displacement signal has a frequency equal to the natural frequency of the RLG block in the torsion mode of oscillation (typically between 300–500 Hz) while the max frequency of the oscillatory motion of the body on which RLG is strapped is unlikely to exceed a few tens of Hz. Hence a notch filter whose center frequency is equal to the Dither frequency is used to remove the Dither component. A Low Pass Filter which allows the signal representing external angular displacement to pass through the minimal attenuation/distortion but rejects the dither displacement signal as well as the quantization noise could serve as an effective means of stripping the dither information from the composite signal. In our system the digital dither-stripping filter has been implemented in DSP. A notch filter (8th order Butterworth IIR filter) has been used for Dither removal. It is followed by a 4th order LPF (Inversed Chebechev IIR filter) to remove the quantization noise. The composite signal sampled at 10 KHz, is the input data to this filter and the output of this filter is digitized representation of the displacement of the body over the duration of sampling interval.

The choice of the number of taps (points) used in a filter realization is a compromise; increasing the no. of taps enhances the filter response producing a flatter pass band and a narrow pass band to stop band transition region, but leads to a greater delay between the input and the output. This filter produces a time delay of 4.5 msec. Since this filter has been implemented using integer arithmetic, all coefficients of this filter has been scaled to a factor 212 and the resulting filter output has been scaled down by the same factor to yield the final output. Simulation studies indicate that the response of the resulting filter with the truncated coefficient well meets the requirement. An attenuation figure of 60 db has been chosen as it completely eliminates the dither signal from the final output.

Filter Design Criteria:

Filter Type: Inv-Chebyshev, Band Pass.   Filter Order: 6th.

Min Attenuation in Stop Band: 56 dB.

Lower Cut-Off Freq: 325Hz.

Upper Cut-Off Freq: 500Hz.

The magnitude and phase response obtained from simulation studies is shown below. It is to be noted that the phase response of the filter is almost linear over the frequency range of interest (gyro bandwidth), namely 0 – 100 Hz. The phase lag is 43.52 degrees at 100.1Hz, and the resulting time delay is 1.208 ms. Since the phase response is linear, the group delay (≈ 1.2 ms) is constant over the frequency range of interest.

Frequency response of the Filter:

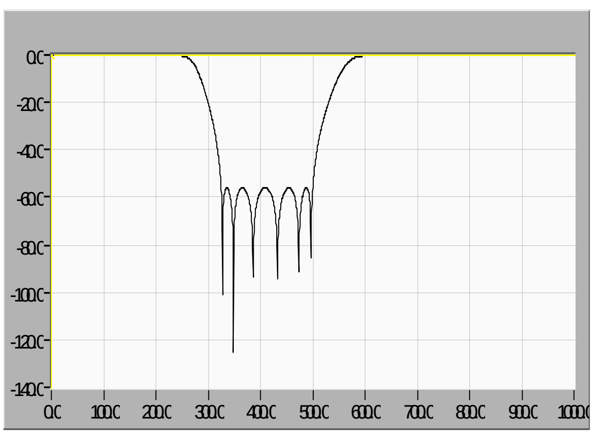


Fig2. Magnitude response:(Magnitude in dB. vs. Frequency in Hz)

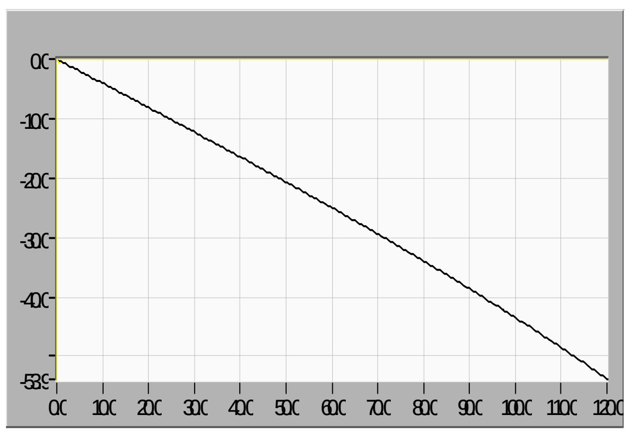


Fig3. Phase response: (Phase in degrees. vs. Frequency in Hz)

3. COMPUTATIONAL REQUIREMENTS OF RLG BASED INS-GPS SYSTEM

The Processor module in INS-GPS System implements the following functions

1. Built-in self test (BIST)
2. Sensor data acquisition and error compensation
3. Attitude update, incremental position and velocity update
4. GPS receiver data acquisition and validity checking
5. Data fusion using Kalman filter
6. Flight management functions and data posting to on-board computer

All these functions are carried out using Analog Devices Digital Signal Processor ADSP-21060.

After power on, the navigation processor performs the built in self tests for sensors health, peripherals checks, and interfaces and so on. The navigation processor has to acquire the three orthogonally mounted RLGs and accelerometer data and compensate the sensor data for errors like bias, misalignment and scale factor deviations and execute the coning and sculling algorithm to extract the true rotational rate in real time. Quaternions are computed based on four sample Miller's algorithm. Pure navigation algorithm is to be executed to compute the incremental position and velocity. Navigation processor has to acquire GPS receiver data at a faster rate and check the validity of data. The data fusion of pure navigation and GPS is done using a 17 state Kalman filter. The pure and hybrid navigation data is to be posted to flight computer. The navigation processor module is also responsible for all flight management functions like wise NRAM data storage in power failure condition, health checks of various peripheral interfaces.

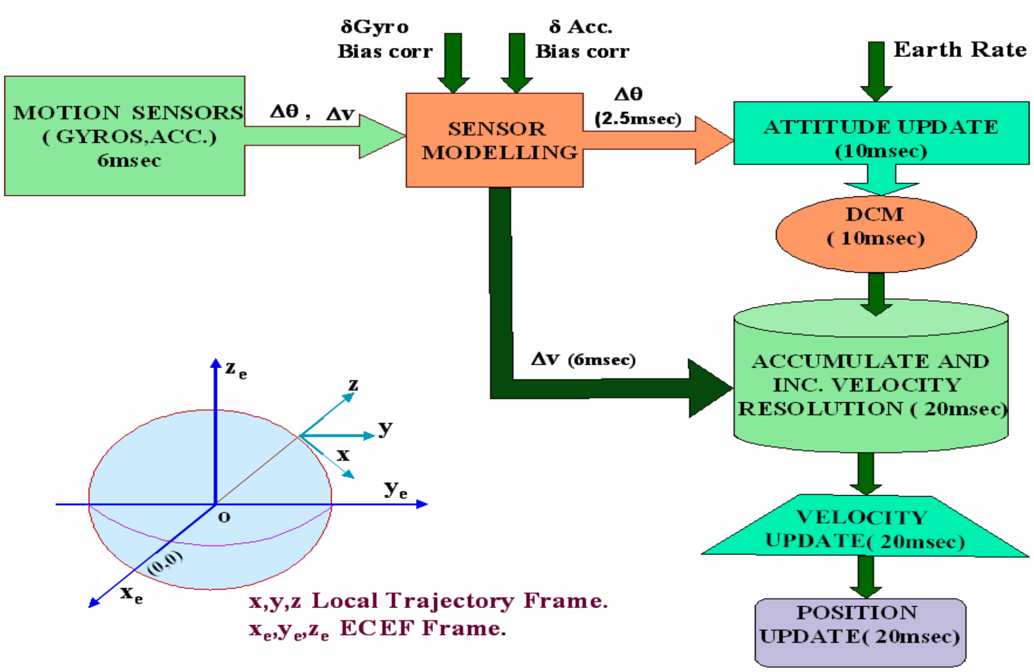


Fig4. Pure Navigation Scheme implemented on ADSP-21060

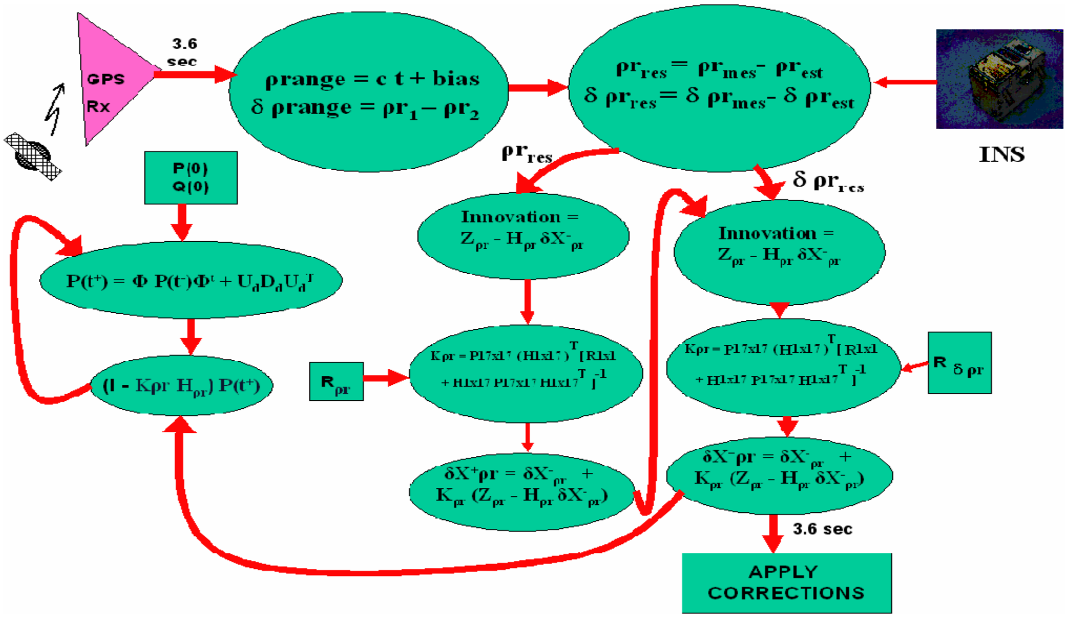


Fig5. Data fusion using Kalman Filter implemented on ADSP-21060

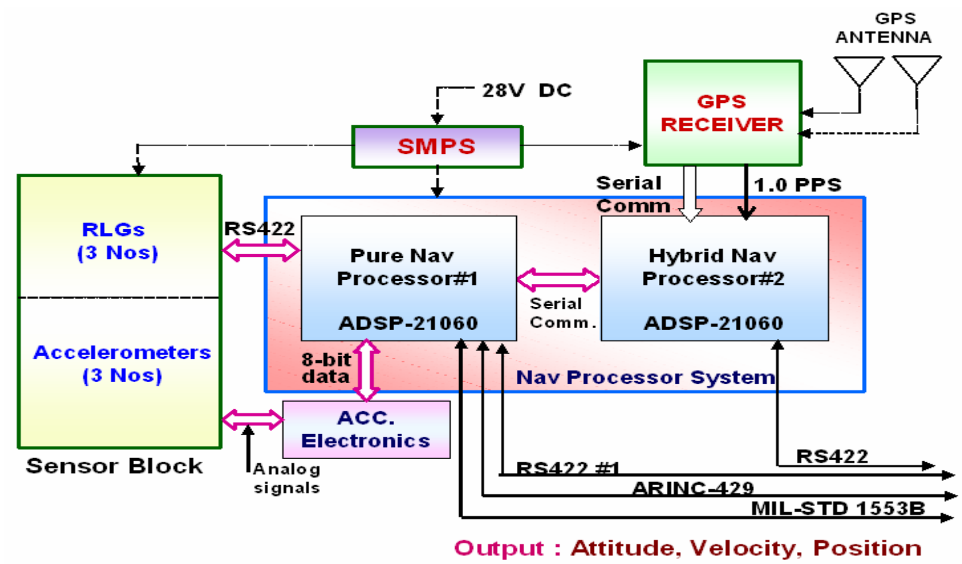


Fig6. Block diagram of Navigation Processor module

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