Looking for stability

Analysing the frequency response of inertial MEMS sensors in stabilisation systems. By **Mark Looney**.

Platform stabilisation systems employ closed loop control systems to actively cancel vibration and other undesirable motions. Fig 1 shows a generic platform stabilisation system where servomotors correct for angular motion. The feedback sensor provides dynamic orientation information for the instrument platform. The feedback controller processes this data and translates it into corrective control signals for the servo motors.

Many stabilisation systems require more than one axis of active correction, so inertial measurement units (IMUs) often include at least three axes of gyroscopes (measuring angular velocity) and three axes of accelerometers (measuring acceleration and angular orientation) to provide the feedback sensing function. Since there is no 'perfect' sensor, IMUs often employ two or three sensor types on each axis. Amongst the sensors that might be used are accelerometers, gyroscopes and three axis magnetometers. While many systems use only accelerometers and gyroscopes, magnetometers can improve measurement accuracy in some systems.

Fig 2 shows how gyroscope and accelerometer measurements can be employed in a manner that uses their basic strengths, but which minimises their weaknesses. The pole locations of the low pass accelerometer and high pass gyroscope filters are typically application dependent, with accuracy goals, phase delay, vibration and 'normal' motion expectations all contributing to these decisions. System dependent behaviours will also affect the weighting factors, which also have an impact on how these two measurements are combined. The extended Kalman filter is one example of an algorithm that combines filtering and weighting functions to calculate dynamic angle estimates.

When developing a stabilisation system around a new MEMS IMU, it is important to understand the frequency response in the early stages of system design, as this will have a direct impact on the design and will help to identify potential stability issues.

Frequency response is often shown as 'bandwidth' in specification tables for IMUs and gyroscopes. As a parameter, it shows the frequency at which the output magnitude drops to about 70% (–3dB) of the magnitude of motion the sensor is experiencing. In some cases, bandwidth may also be defined by the frequency at which the output response lags the actual motion by 90° (for a two pole system). Both metrics can impact an important control loop stability criterion: unity gain phase margin – the difference between the phase angle of the loop response and –180° at a loop gain of 1. Understanding the frequency response of the feedback sensor is key to optimising the tradeoff between stability assurance and system response. In addition to managing stability criteria, the frequency response also has a direct impact on vibration rejection.

Analysing frequency response starts

Fig 1: A basic platform stabilisation system

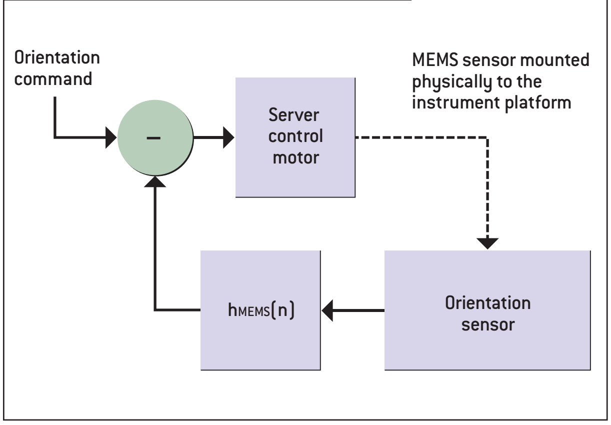


Fig 2: Combining single axis sensor outputs

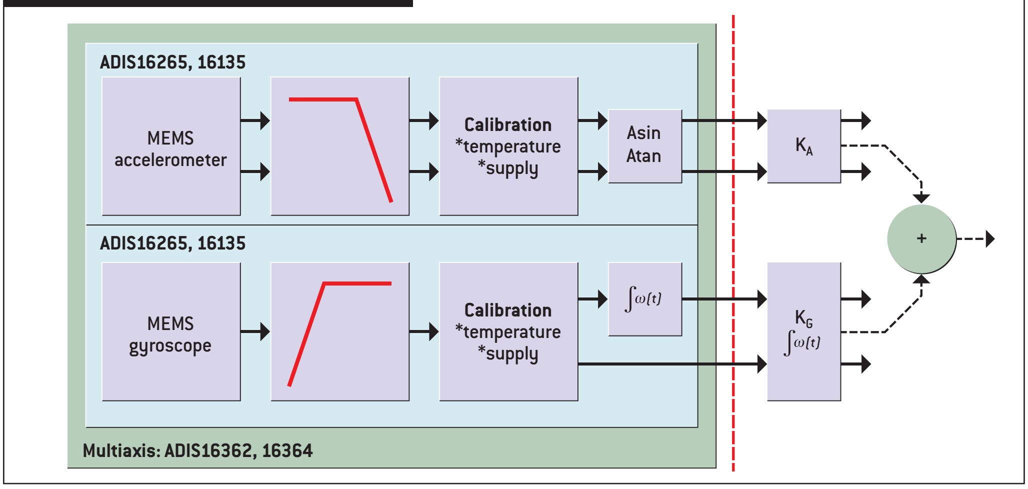
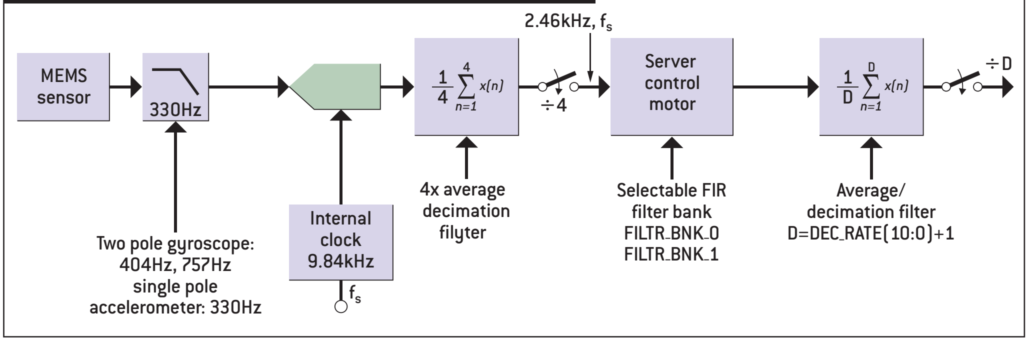


Fig 3: An ADIS16488 sensor in a frequency analysis signal chain



with a high level view, which describes the system's response to inputs over the frequency range of interest. For an inertial MEMS system, the input is the inertial motion the IMU experiences and the outputs are often represented by digital codes. While s-domain analysis techniques are valuable, developing a complete transfer function for this type of system often requires additional techniques and consideration.

The analysis process starts with understanding the components in a sensor signal chain (see fig 3). If the bandwidth is not limited in the sensor element, it is often limited by filters in the signal conditioning circuit preceding the a/d converter. After the signals are digitised, a processor typically applies correction (calibration) formulas and digital filtering. Secondary digital filters reduce the bandwidth and sample rates the feedback systems use in their control routines.

All these stages can influence the gain and phase of the sensor signal with respect to frequency.

Inertial frequency response test

The most direct approach for testing a gyroscope's frequency response is with an inertial rate table, which typically includes a programmable servo motor and an optical encoder that verifies programmed rotation on the motor shaft. While this approach applies actual inertial motion, it is not commonly available for engineers who getting started with MEMS.

For early analysis validation without a rate table, measuring spectral noise over the frequency band of interest can provide useful insights. This approach does not require sophisticated test equipment, only a secure mechanical connection to a stable platform and data collection instrumentation. However it does rely on mechanical noise having a 'flat' magnitude with respect to frequency.

Recognising resonant behaviour can be valuable for those modelling and simulating a control loop. Identifying this behaviour in a simple test can also help to explain higher than expected noise levels when performing a more thorough system characterisation. When understood and identified early in a project, these behaviours can normally be managed with adjustments to the filter poles.

When measuring noise density, make sure the sample rate is at least twice the highest frequency of interest to meet Nyquist and take enough data samples to reduce measurement uncertainty.

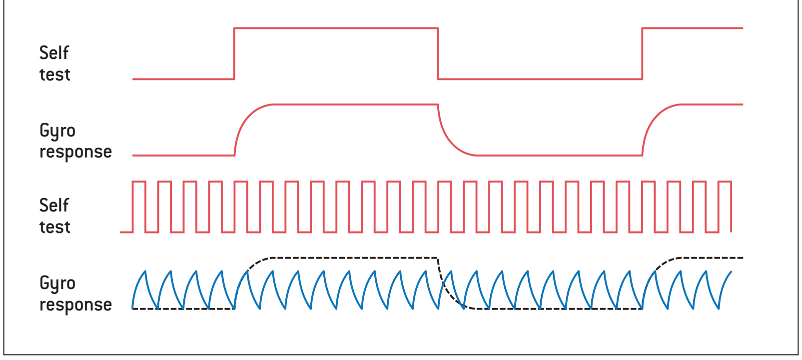
Another approach uses a gyroscope's self test function. This forces a change to the internal structure, which changes the sensor output. Not all products provide real time access to this, but it can be a useful tool when available, or if the manufacturer can provide data from this type of frequency response test.

In the simplest approach, the response from the self test is compared with the analytical expectation. Repeating self test at specific frequencies provides a direct method for studying the magnitude of the sensor response at each frequency.

Consider the two responses in fig 4. At the lower frequency, the gyroscope's output looks like a square wave, with the exception of the transient response at each transition. This follows the expectation of a 'step response' for the filter network in the sensor signal chain. In the second example, where the self test frequency is high enough to prevent full settling, a decrease in magnitude occurs. Notice the difference in magnitudes between the blue and black dotted responses on the bottom signal. A number of methods can be used to estimate the magnitude of these time records.

Developing an understanding of an IMU's bandwidth and its role in system stability should employ: analysis; modelling; test data; and iteration of these factors. Start by quantifying the information available, make assumptions to close any gaps and then develop a plan to refine these assumptions.

Fig 4: Self test waveforms



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