Rarely Asked Questions—Issue 131 Going Full Tilt

By lan Beavers



Question:

I would like to improve the accuracy and repeatability of tilt measurements using the ADIS16209 inclinometer. Can I use several of these sensors in parallel to improve the accuracy?

Answer:

Yes, theoretically, this technique can help the accuracy performance of the inclinometer measurements by creating an averaging effect using multiple sensors. The reason for the potential benefit is that the uncorrelated error sources and random noise between multiple sensors can be averaged out. This lowers the overall noise floor of the aggregated sensor data and allows the aggregated signals of interest to be larger in power relative to the noise. While MEMS design teams turn out world class sensors, system engineers will continue to look for the last piece of incremental performance. However, *caveat lector* is in order as this is not an absolute case and there are some areas of system design that must be taken into account.

The output of two inclinometer sensors can be summed and averaged using back-end digital processing within a microcontroller. The primary headline specification for an inclinometer is the relative accuracy of the sensor tilt to the horizontal plane. By combining the signal outputs, the noise density is reduced similar to that of a 2× oversampled condition. Similarly, combining the signal outputs of four inclinometers and averaging them can yield a 4× improvement scenario. In ideal terms, a 0.1° accuracy could theoretically be reduced to 0.025° using four parallel inclinometers.

Subtle, internal nonlinearity mismatch between inclinometers will exhibit unique transfer curves. While some nonlinearities will be similar due to architecture, others will be different due to part-to-part variances. These will manifest as overall noise sources along with general random sensor noise. We can lump these into one category called *noise*. In general, the noise is predominantly uncorrelated from one to the other. The primary benefit of using a multiple sensor system approach is to average out this white, random noise. Conversely, when unwanted signals that are correlated in phase and frequency are summed, their magnitudes will combine additively and provide no benefit to the parallel sensor approach.

When two uncorrelated signals, such as white noise, are summed together, they combine mathematically as a root-sum-square (RSS). This results in a magnitude increase by a factor of $\frac{\sqrt{1+1}}{2} = 0.707$ for two equal amplitudes. If $V_{\text{noise_rms}} =$ noise on one sensor input, then the average noise on two channels would be:

$$\frac{\sqrt{V_{noise_1_rms}^2 + V_{noise_1_rms}^2}}{2} = \frac{\sqrt{2} V_{noise_rms}}{2} = 0.707 V_{noise_rms}$$

By adding two identical instances of the same correlated signal and averaging, the power will nearly be the same (2× addition of the same signal divided by 2) and the random noise will decrease by half the power of the signal. This yields an ideal increase in 3 dB signal power of the overall averaged signal-to-noise ratio (SNR). Any mutually exclusive nonlinearities or noise subjected to only one of the parallel sensors that is not presented to the other will degrade some portion of the full benefit.

However, there are several details of the parallel sensor system design that could prevent the full benefit of a 2× or 4× reduction in the accuracy. First, the inclinometers need to be influenced equally by the same signals across the comparative axes of the devices. Spatial differences on a printed circuit board may produce different observations by each inclinometer. Unique offsets may exist due to system-level influences, such as PCB thickness variation and solder volume tolerances. Second, parallel axis alignment between the sensors should be matched. Standard variances in assembly across a board



Figure 1. For a two-axis inclinometer such as the ADIS16209, the relative placement angle accuracy of the x-axis and y-axis alignment will impact the full benefit of a multisensor parallel averaging system. For a three-axis accelerometer system, the flatness or tilt of parallel devices about the x/y plane will impact the z-axis alignment between multiple sensors.

will have placement and theta tolerances that need to be considered. Lastly, part-to-part axis alignment error and nonlinearity mismatch can also impact the best design and assembly. This metric establishes how perpendicular the x-axis and y-axis are at 90° to one another. The sensor's data sheet outlines these specifications.

At the time that the system is commissioned, any known assembly differences should be horizontal calibrated in order to realize the maximum parallel benefit. For example, measured offset bias errors can be nulled and zero adjusted across the inclinometers to reference a known position. The ADIS16209 provides an autonull option as a means to overcome these offset factors.

Additional Sources for ADIS16209 Information:

ADIS16209 Data Sheet: High Accuracy, Dual-Axis Digital Inclinometer and Accelerometer.

ADIS16209 Evaluation Tool Overview.



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