Technical Article

Accuracy? Resolution? Arc Minutes? How to Take Charge of Your Motor Control Design

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Imagine your commute this morning in your car. The traffic light turned green, and you pushed the accelerator as soon as you could. Your car responded within seconds and you continued on toward the office. But behind the scenes, inside your car, there was a lot more happening. Let's take a look.

When you press the pedal, the motor does its best to provide the necessary torque to your car through the shafts. The traction motor drives your vehicle forward. This motor (typically a three-phase synchronous motor) is controlled by complex circuitry that consists of several transistors, as well as motor driver, protection and feedback control. The feedback control signal comes from motor position sensors (see Figure 1). These sensors give an analog angle output signal (remember, all real-world signals are analog). This continuous analog signal is converted into the digital domain with the help of an analog-to-digital converter (ADC). Ideally, you could break the continuous analog signal into an infinite number of digital steps, but in the real world, the quantization of an analog signal by the ADC happens in a finite number of steps leading to an error, known as quantization error. Here is where the terms "accuracy" and "resolution" kick in.

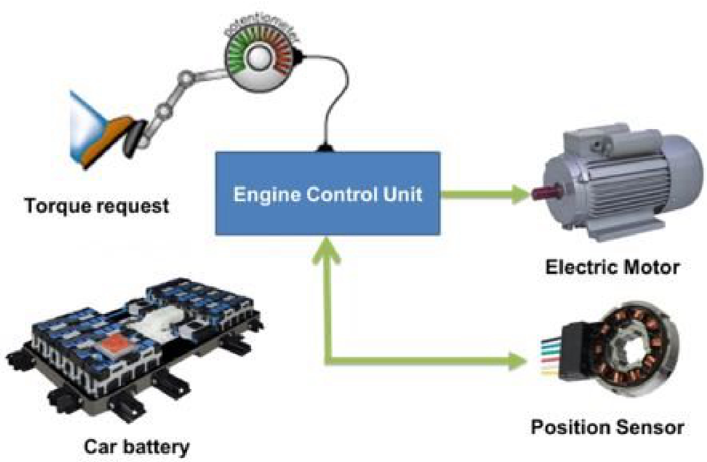

Figure 1. Typical System Block Diagram of a Motor-control System in a Vehicle

Accuracy

Take as an example a 12-bit resolver-to-digital converter (RDC). Over one revolution of a shaft, the output of the converter has 2^{12} = 4,096 digital codes. In the motor-control world, step size is usually defined in terms of arc minutes or arc seconds. There are 60 minutes in one degree and 360 degrees in one revolution. Thus, over a circle, you have 360 × 60 = 21,600 arc minutes. Since there are 4,096 digital codes, each division is spaced by = 21,600/4,096; that's 5.27 arc minutes. 5.27 arc minutes corresponds to one least significant bit, or 1LSB. Thus, even when the input angle (a continuous signal) is 100% accurate, the output digital code cannot move by more than 1LSB (or 5.27 arc minutes) before the next code. The RDC specifies this accuracy number by taking into account offset, gain and linearity errors. For reference, the typical accuracy specification for a brushless resolver is 10 arc minutes. The typical error for the entire resolver system, adding the sensor and the conversion error, is approximately ±15.273 arc minutes (10 arc minutes for the resolver sensor and +5.273 arc minutes in my example). These numbers will help us select the appropriate sensor solution for the system, which are typically constrained by these specifications.

Resolution

So, what does resolution mean? “12-bit” resolution means 2^{12} distinct output codes over a 360-degree angular rotation. The actual resolution is simply the number of bits available at the output of the RDC; note that not all of these bits are noise-free. The effective resolution refers to the true “useful” bits from an analog-to-digital conversion, taking into account the signal noise. These are the effective number of bits (ENOB). ENOB is often confused with the resolution stated in the product data sheet.

What Does 1 LSB Mean?

So far, we’ve reviewed what accuracy and resolution means. Now, let’s take this knowledge and apply it to a system where accuracy and resolution are usually specified in terms of LSBs. Are you wondering how to make sense of an LSB from a systems context? First, let’s look into what 1 LSB translates to in the motor control world, relating to arc minutes and degrees. Here are two examples, 12-bit and 10-bit:

In the 12-bit world, 1 LSB equates to:

$1LSB = 360 \div 2^{12} = 0.087$ degrees = 5.27 arc minutes = ±2.64 arc minutes = ±0.04395 degrees

Similarly, in the 10-bit world, 1 LSB equates to:

$1LSB = 360 \div 2^{10} = 0.351$ degrees = 21.09 arc minutes = ±10.54 arc minutes = ±0.1757 degrees

Conclusion

Isn’t it exciting to see what happens behind the scenes in your car? Accuracy and resolution are the fundamentals of selecting the appropriate sensing solution for your specifications. When accuracy is better than resolution, the converter’s transfer function is precisely controlled over the number of bits of resolution.

Leave a comment below or visit the TI E2E™ Community Automotive forum to join others talking about rotary position sensing.

Additional Resources

- Read the Analog Applications Journal article, *“*Design considerations for resolver-to-digital converters in electric vehicles.*”*
- To learn more about resolver sensing in industrial applications, read the white paper, “Electrical design considerations for industrial resolver sensing applications.”
- Read more about electric vehicle design in part one and part two of this *EDN* article series.
- Jump-start a resolver-based rotary position sensing design with the TI Designs Automotive Resolver-to-Digital Converter Reference Design for Safety Application (TIDA-00796).
- Download these application notes:
  - “PGA411-Q1 PCB Design Guidelines.”
  - “Troubleshooting Guide for PGA411-Q1.”
  - “Software Developer’s Guide for PGA411-Q1.”
  - “PGA411-Q1 Step-by-Step Initialization With Any Host System.”

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