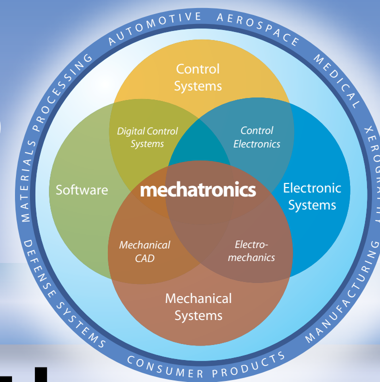
MECHATRONICS IN DESIGN

FRESH IDEAS ON INTEGRATING MECHANICAL SYSTEMS, ELECTRONICS, CONTROL SYSTEMS AND SOFTWARE IN DESIGN



Sensor Fusion - It's Hot!

Complementary filtering to meet demanding performance requirements

BY KEVIN CRAIG

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Every measurement application can be put into some combination of three categories: monitoring of processes and operations, control of processes and operations, and experimental engineering analysis.

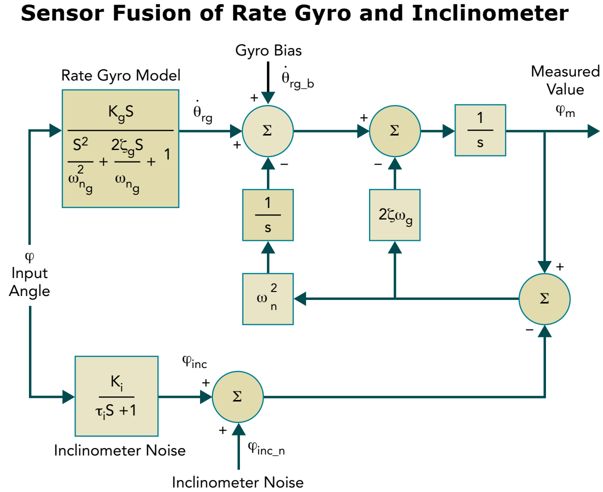
Control is the most important class in mechatronics. Sensors are used in feedback systems and feedback systems are used in sensors. The text "Measurement Systems: Application and Design" by E. Doebelin is the gold-standard reference. It is from there that I learned to apply sensor fusion in real hardware systems, most notably with a team of senior mechatronics students at Rensselaer Polytechnic Institute in 2006. They went on that summer to showcase their Segway-like Human Transporter incorporating sensor fusion during the keynote presentation at NI Week.

When measuring a particular variable, a single type of sensor may not be able to meet all the required performance specifications. We sometimes combine several sensors into a measurement system that utilizes the best qualities of each individual device. Thus, sensors complement each other, giving rise to the name complementary filtering or sensor fusion. The basic concept is as follows: If a time-varying signal is applied to both a high-pass filter and a low-pass filter, and if the two filter output signals are summed, the summed output signal is exactly equal to the input signal.

A mechatronics example, used in the Segway-like Human Transporter, is absolute angle measurement. The two basic sensors used are a microelectromechanical (MEMS) rate gyro and an inclinometer. The inclinometer measures tilt angle relative to gravity vertical by immersing two circular sector capacitance plates in a dielectric liquid. Angular tilting causes one pair of plates to increase capacitance and the other to decrease. These capacitance changes cause a frequency change in an oscillator, which is then converted to a pulse-width-modulated (PWM) signal. By low-pass filtering the PWM signal, a dc voltage proportional to tilt angle is obtained. A rate gyro gives a dc voltage output proportional to angular velocity, with a flat frequency response to about 50 Hz. Op-amp analog integration of the gyro signal would give us angular position, but the bias error quickly gives an unacceptable, ever-increasing drift of the position signal. The inclinometer does not suffer from a drift problem (no integration is involved) and can thus be used to correct for the gyro drift problem. It cannot; however, be used by itself for angle measurements in applications that require a fast response (like measuring vehicle motions) since it is a first-order instrument with low bandwidth, typically 0.5 to 6 Hz, too slow for many applications. The two sensors are thus good candidates for a complementary-filtering application, giving both angular position and angular velocity data over about a 50-Hz bandwidth with negligible drift.

While the configuration of the separate high-pass and low-pass filters is most useful for explaining the basic concept of complementary filtering, the practical implementation instead uses a feedback type of configuration that produces identical differential equations and transfer functions. Also, realistic sensor models should be used for analysis and simulation purposes. The inclinometer is modeled as a first-order system and the rate gyro is modeled as a second-order system.

Sensor Fusion of Rate Gyro and Inclinometer



Sensor fusion is another important tool for the mechatronics engineer's toolbox.

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