Precision MEMS Sensors Enable New Navigation Applications

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IDEA IN BRIEF

When it comes to navigating indoors and addressing complex and environmentally challenging scenarios, sensors can be employed to improve a system's ability to determine actual from anomalous motion.

Navigation is typically associated with cars, aircraft, and ships. Within the industrial and medical segments, however, precision navigation is becoming more widely used in applications ranging from factory machinery and surgical robots to first responder tracking. There are many existing approaches to derive location, direction, and movement as they relate to pointing, steering, and guiding equipment. In fact, it has become common for many applications to rely on GPS (global positioning system). But when it comes to navigating indoors and addressing more complex and environmentally challenging scenarios, GPS alone is insufficient.

For these kinds of applications, various sensor types can be employed to improve a system's ability to determine actual from anomalous motion. The ability of a given sensor to address a particular navigation problem is not only dependent on the performance level of the sensor but also on the unique dynamics of the application. As with any complex design problem, the starting point is to understand the end application objectives and limitations. From there, the critical performance parameters can be ranked to arrive at a rough understanding of the needed sensors, followed by actual design optimization through careful sensor conditioning, integration, and processing.

UNDERSTANDING THE NAVIGATION PROBLEM

Let's begin with an analogy: say you are at work and want a cup of coffee, so you navigate to the coffee pot. If you've been there before, you have a route in mind, but along the way you rely on various senses to get you there, including optical, audio, balance, even perhaps touch. Your own personal processor combines these various sources, along with some embedded pattern recognition and, if it is a rough day, you may need to pause and ask for some external input,

that is, directions. Throughout this process, you rely on your personal sensors not only to be individually precise but also to work well together, to reject misleading information when necessary (that is, the smell of coffee from your neighbor's cubicle), and to rely on the other sensors. To reach your destination, you employ the same techniques used by designers of navigation systems for vehicles, surgical instruments, and robotic machinery.

The industrial corollary to this example includes various sensing techniques, none of which can single-handedly address most applications. As referenced earlier, GPS is prone to errors due to obstacles that block satellite reception, either lowering the overall accuracy or the update rate. Another common navigational aid, the magnetometer, requires clear access to the earth's magnetic field and, while this can generally be assumed, there are many field interferences within industrial environments that make a magnetometer's reliability intermittent at best. Optical sensors are subject to line-of-sight obstructions, while inertial sensors are generally free of these interferences but do have some of their own limitations, for example, the lack of an absolute reference (where is North?). The relative strengths of and potential issues with major navigation sensor types are outlined in Table 1.

Table 1. Strengths/Limits of Sensors

Sensor Type	Major Advantage	Potential Limitations
GPS	Long term absolute reference	Possible blockages
Magnetic	No required infra-structure (except earth)	Subject to interference
Optical	Intuitive	Line of sight obstruction
Inertial	Self-contained	Relative, not absolute, reference

SENSOR SELECTION AND PROCESSING

Except for the simplest of problems, most solutions rely on multiple sensor types to deliver the required accuracy and performance under all conditions. Inertial sensors, such as micro-electro mechanical system (MEMS) based accelerometers and gyros, provide the potential to fully compensate for the shortcomings of other sensor types because they are free from many of the same interferences and do not require

external infrastructure (no satellite, no magnetic field, no camera…just inertia).

MEMS inertial sensors are highly reliable (with a 20 year track record in the automotive industry) and commercially attractive, offering lower power, size, and cost as demonstrated by their successful application in mobile phones and video games. However, there is a large variation in available performance levels, with devices suitable for gaming not able to address the high-performance navigation problems outlined previously. Precision industrial and medical navigation, for example, typically require performance levels that are an order of magnitude higher than is available from MEMS sensors used in consumer devices.

In most cases, a device's motion is relatively complex (more than one axis), which drives the need for full inertial measurement units (IMUs), which may integrate up to six degrees of freedom of inertial movement—three linear and three rotational (see Figure 2).

For example, the Analog Devices ADIS16334 *i*Sensor IMU has the integration and performance necessary for most industrial navigation problems in a compact format that is amenable to many industrial instruments and vehicles (see Figure 1). In many cases, four or more additional degrees of freedom can also be integrated, including three axes of magnetic sensing and one axis of pressure (altitude) sensing.

Figure 1. Six Degrees of Freedom Motion Detection in an 11 mm × 22 mm × 33 mm Package

As described earlier, any sensor type has limitations, and if those limitations can disrupt system performance goals, a designer may choose to both implement compensation techniques and merge multiple sensor types. For instance, an inertial measurement unit outputs highly stable linear and rotational sensor values, which must compensate for the following influences:

- Temperature and voltage drift
- Bias, sensitivity, and nonlinearity
- Vibration
- X, Y, Z axis misalignment

Inertial sensors can have varying degrees of drift depending on their quality, and GPS or a magnetometer can also be employed to occasionally correct for that drift. A central challenge in navigation, beyond good sensor design, is determining which sensors to rely on and when. Inertial MEMS accelerometers and gyros have proven that they are a good complement to help designers design a full functioning sensing system.
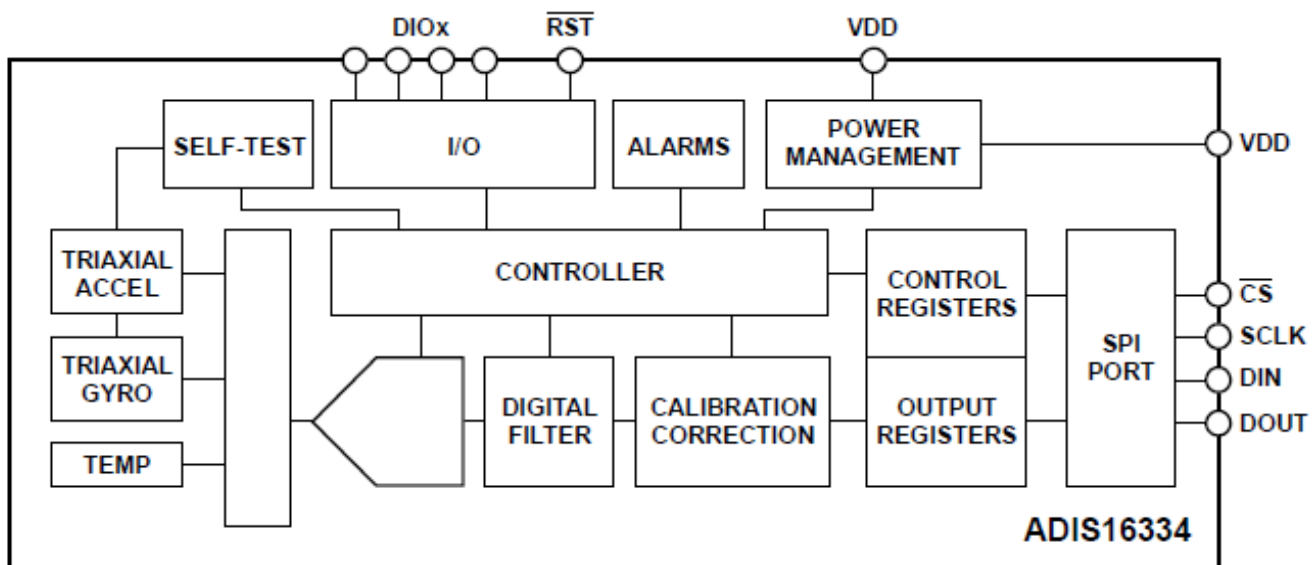

Figure 2. Inertial Measurement Units Capture Complex Multiaxis Motion

DESIGNING WITH MEMS INERTIAL SENSORS

In an indoor industrial or medical setting where the GPS signal is denied and machinery and electronics introduce magnetic interference, designers must establish less traditional approaches to machine guidance. Many emerging applications, for instance surgical tool navigation, also require significantly higher levels of precision than, for instance, automobile navigation. In all of these cases, inertial sensors can be an option and provide the dead-reckoning guidance required to maintain accuracy during the line-of-sight blockage or other interference sources detrimental to noninertial sensors.

Figure 3 depicts a generic inertial navigation system (INS) that can be used to navigate anything from a vehicle, to an aircraft, to a surgeon's tool. The INS model incorporates a Kalman filter, which was first used on the Apollo moon missions and today is pervasive in phased-locked loops within mobile communication to provide a mechanism for merging multiple good but imperfect sensors and providing the best estimate of location, direction, and overall motion dynamics.

When applied to surgical applications, the INS could be used as a navigational aid for aligning artificial joints, such as knees or hips, according to a patient's unique physical characteristics.

Besides the goals of better alignment for improved comfort, and faster and less invasive surgery, the right sensors can also help counter hand tremor and fatigue. Purely mechanical alignment has been supplemented by optical alignment in recent years, but like GPS blockages for vehicle navigation, there are potential line of sight blockages in the operating room that limit optical sensor accuracy. An inertial-guided surgical alignment tool can supplement or even replace optical guidance, with no line of sight issue, and also offer potential advantages in size, cost, and automation.

Though the basics of solving a navigation problem have much consistency across applications, the end-system specifics must be well understood. These ultimately guide the selection of appropriate sensor types, as well as the overall performance.

In parallel with a strong push for small, low power, multiaxis inertial sensors for consumer applications, there is an equally strong focus by some sensor developers on high accuracy, under all conditions, for compact low power high performance sensors. These high accuracy, environmentally robust sensor developments are driving a new surge in the adoption of MEMS inertial sensors within the industrial, instrumentation, and medical markets.
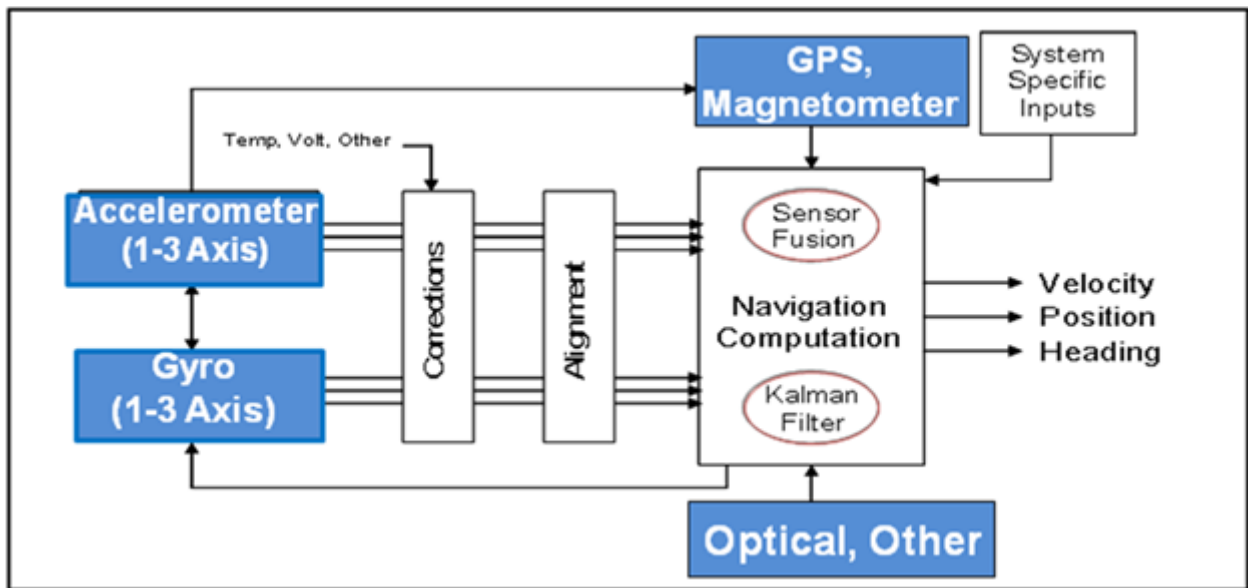

Figure 3. Inertial Navigation System, Merging Multiple Sensor Types with the Aid of Kalman Filtering

RESOURCES

For more information, visit www.analog.com.

Products Mentioned in This Article

Product	Description
ADIS16334	Low-Profile, Six Degree of Freedom Inertial Sensor

ANALOG DEVICES