

TECHNICAL ARTICLE

Smart Farming Revolution: How Inertial Sensing Is Driving Precision and Productivity

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Abstract

The pressure to sustainably feed a growing population worldwide is leading to the adoption of more technology and automation in modern smart farming. Inertial sensors have a role to play in several different applications. Precision inertial measurement units are being used for navigation and stability of the increasing roboticization of the industry, including self-steering tractors, picking robots, drones, etc. Furthermore, wideband inertial sensors can be used for predictive maintenance of all this complex machinery. Lastly, inertial sensors help enable various edge sensing modalities like animal tracking, detecting heat in dairy animals, and vital sign monitoring.

Introduction

The world's population is projected to reach nearly 10 billion by 2050, necessitating a 70% increase in food production worldwide as standards of living increase across the globe.¹ Yet, the agri-market faces unprecedented challenges. Many developed and developing nations face a shrinking agricultural workforce. Younger generations are moving away from traditional farming, and labor costs continue to rise. Compounding the challenge is our changing climate, where unpredictable weather patterns, soil degradation, and water scarcity present daunting challenges to farmers across the globe. Agricultural businesses must maximize yields, reduce waste, and optimize costs to keep up with demand and remain competitive. This is where technology has a strong role to play. The rise of artificial intelligence (AI), machine learning (ML), robotics, and Internet of Things (IoT) has made automation in smart farming more feasible and cost-effective. Farmers now have access to data-driven insights that improve decision-making.

Automated systems, such as robotic harvesters and drone-assisted monitoring, allow for faster, more efficient farming

operations and reduce dependence on manual labor. Precision farming techniques improve soil health, seed placement, and crop growth, leading to higher yields per acre. Smart irrigation and fertilization systems minimize water and fertilizer waste, leading to cost savings and resource conservation.

In the world of smart farming, inertial sensors play multiple critical roles. First and foremost, inertial sensors provide real-time data on acceleration, orientation, and position, improving the efficiency of autonomous and semi-autonomous (autosteer) farming vehicles. Inertial measurement units (IMUs), aided by GPS, are used to navigate and steer land and air vehicles such as tractors, robots, and drones, monitor their attitude and other inertial states, and enable these vehicles to follow precision paths for seeding, tilling, and spraying that ultimately reduce cost and improve the sustainability of farming. Second, in livestock management, inertial sensors can be used to track animal movement and behavior, allowing farmers to monitor herd health and detect anomalies in activity patterns. Lastly, the integration of inertial sensors with AI-driven further improves the predictive maintenance of farm equipment, reducing downtime and maintenance costs.

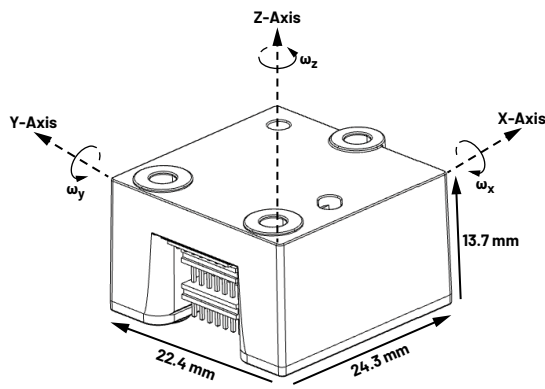


Figure 1. The ADIS16576 inertial reference frame.

Advancements in micro-electromechanical systems (MEMS) technology have led to enhanced performance, making MEMS IMUs pivotal for scalable autonomous vehicle (AV) platforms. MEMS IMUs often serve as feedback sensing elements in motion control systems, such as guidance navigation control (GNC) in autonomous vehicles or in pointing control for smart implements (sprayers, seeders, scoops, blades). When used as a feedback sensing element, MEMS IMU performance has a direct impact on a system's accuracy. The ADIS16576 is a recent example of a MEMS IMU that delivers advancement in both functional integration and core sensor performance (Figure 1). This device offers a substantial leap forward, with the most impactful behavior coming from a 10× improvement in gyroscope vibration rectification error (VRE) and a 50× improvement in accelerometer VRE. On the most basic level, MEMS IMUs provide triaxial angular rate sensing around three mutually orthogonal axes (roll, pitch, yaw) while also providing triaxial linear acceleration sensing along the same three axes. The accelerometers provide mean (or static) angle estimation while integrating

gyroscope measurements provides real-time angular displacement. System processors combine these two angle estimation sources to produce credible feedback control information for GNC or pointing control systems. When operating in this way, having an accelerometer VRE of 1.3 mg, under 4 g rms of vibration, means that the GNC platform can preserve an attitude angle of better than 0.1° without requiring assistance from any other sensing function. This can be very useful for UAVs that may experience substantial changes in vibration, depending on thrust levels. In gyroscopes, VRE can create quick and persistent changes in bias, which can result in erroneous motion correction and, in the worst cases, can lead to instability in the platform. In prior generation devices, VRE responses could exceed 300°/h, under 8 g rms, while the ADIS16576 offers a response of 12°/h, which greatly reduces the burden of estimation/correction by other system sensing modalities. One of the most important functional improvements of this MEMS IMU is in the scalable external synchronization. By including a user-programmable, clock scaling function, system developers can now drive 4000 Hz IMU data sampling with slower system-level references, such as the GPS or a video sync. This offers both tight coupling with pulse per second (PPS) or perception sensing references while preserving all the digital processing options that higher data sampling provides. Figure 2 and Figure 3 illustrate an example where an autonomous vehicle platform will use a 20 Hz GPS reference and a 200× scale factor to produce an internal sample rate of 4000 Hz. In addition, this system illustrates the use of an on-board decimation filter to reduce the output data rate by a factor of 20× (200 Hz). In more dynamic situations, such as a crop inspection drone operating in windy conditions, the system processor may need to read and process the data at the maximum sample rate to assure stability and maneuverability.

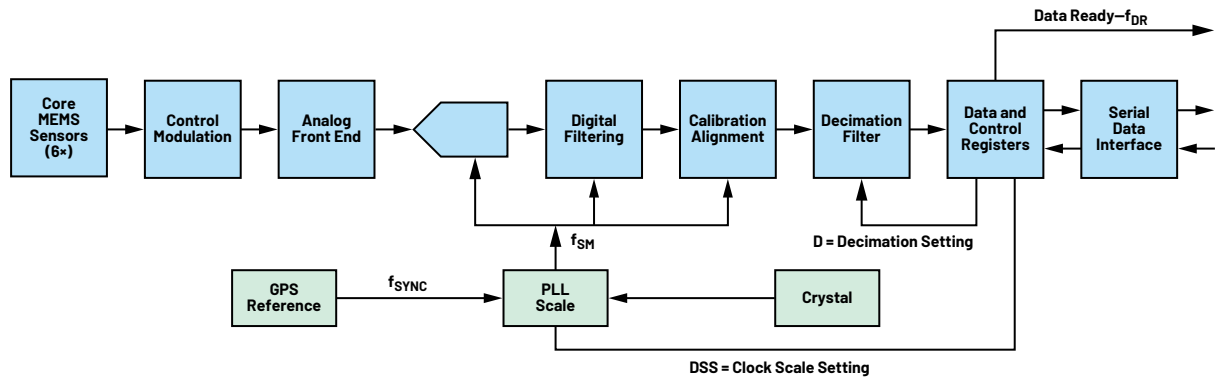


Figure 2. The ADIS16576 signal chain and external synchronization inputs.

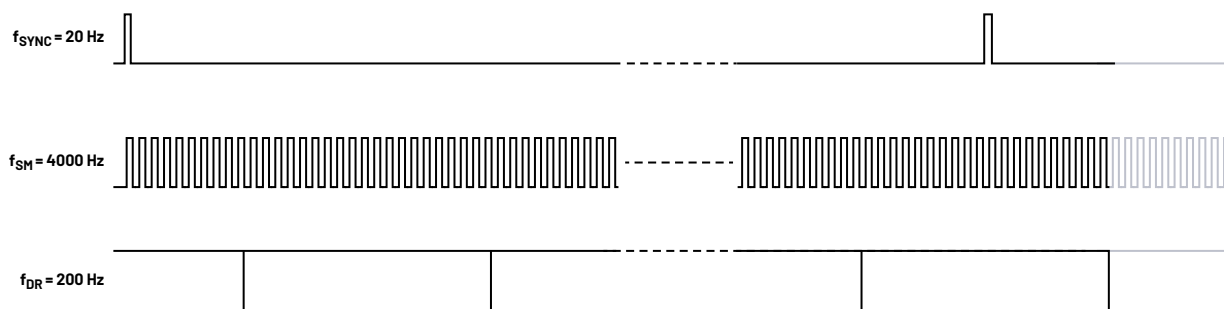


Figure 3. Timing diagram of the ADIS16576 in scale sync mode.

Another area where inertial sensors are providing critical capability is in the use of IoT systems, which are used to continuously monitor animal location and physiological conditions. Typical embodiments include either tags, tacked to the ear, tail, or body, and smart collars worn around the neck. These tags can help manage herd location and, more importantly, give continual insights into animal welfare, such as activity, feeding time, and respiration rate, and newer capabilities that offer the ability to track heart rate and other vital signs. Neck-mounted collars have become invaluable tools for detecting estrus (heat) in cattle, rumination, lameness, and other conditions. A core requirement in these IoT systems is power consumption because maintaining batteries (rechargeable or primary) in large herd populations is an intractable chore. The [ADXL366](#) offers unprecedented capability in this respect. This triaxial accelerometer can directly connect to a battery because it is internally regulated, can operate down to 1.1 V, and can deliver motion data at 100 Hz using approximately 1 μ W of energy. At this level, energy consumption is lower than the self-discharge of a coin cell battery. When used in a neck-worn collar, the accelerometer can scale between low power and low noise modes, providing a minimum signal in the range of 3 mg and 8 mg rms—enough to distinguish between the chewing, rumination, and respiration

rate (R-R). An enhanced vital-sign monitoring capability is offered by the [ADXL380](#), which operates with noise levels that are almost two orders of magnitude lower over a 4 kHz bandwidth. For a fair comparison at 200 Hz bandwidth, the equivalent noise for this accelerometer would be 0.4 mg rms. Such a signal-to-noise ratio (SNR), coupled with the wide bandwidth, can turn this triaxial accelerometer into a stethoscope that can collect heart rate information through a ballistocardiogram or various noises associated with breathing, digestion, and other physiological functions. A comparison between the two accelerometers can be found in Table 1. Another core capability offered by ultralow power inertial sensors is in the system-level power management of IoT nodes. The [ADXL366](#) offers a dedicated wake-up mode that can be used to power cycle electronic systems by issuing interrupts based on detected motion profiles. A typical configuration can be found in Figure 4. The accelerometers offer a rich set of programmable parameters to configure the desired motion profile and, most importantly, wake and sample at full bandwidth. This capability is important to avoid aliasing and false detections. In wake-up mode, the [ADXL366](#) consumes only an astonishing 180 nA. By leveraging this capability, energy hungry sensors, radios, and other components can be powered down when not needed to increase the sensor's node useful lifetime.

Table 1. Side-by-Side Comparison Between Ultralow Power and Ultralow Noise Accelerometers

Product	Full-Scale Range (g)	Resolution (bits)	Wake-Up Current (μ A)	Operating Current (μ A)	Noise (200 Hz) Bandwidth (mg rms)	Bandwidth (Hz)
ADXL366	2 to 8	14	0.18	0.89	8	200
ADXL380	4 to 16	16	33	340	0.4	4000

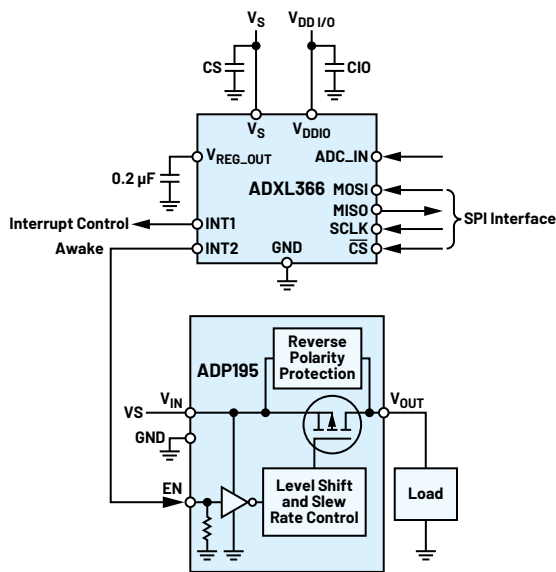


Figure 4. The ADXL366 configured as a motion switch within IoT systems.

The last topic is regarding the integration of inertial sensing and AI analytics for predictive maintenance in smart farming. As the scale of modern farms increases, they are having to rely on high capital expense machinery for production. This type of equipment must deal with precision operation while undergoing strenuous conditions and the rigors of seasonal farm life. Breakdown during the short planting or harvesting season can have a serious financial impact. For example, precision-controlled instruments, such as seeders or harvesters, often have to operate through rain, wind, dust, mud, rock fragments, and many other environmental hazards. In these environments, changes in key vibration artifacts can offer advanced prediction of problems, which can be addressed through maintenance, at times that have minimal impact on peak-demand productivity. Vibration analysis in machinery (analogous to the vital sign monitoring in livestock) can pinpoint the failure mode and timing of different problems in mechanical elements, such as faulty bearings, axle misalignment, imbalance, looseness, gear faults, and other issues. Consider a bearing defect, such as a chip out or any physical deviation from the perfect spherical shape. This will create a bump in the platform every time this defect contacts the machine's surface, resulting in a complex vibration profile that contains both fundamental and broadband content. See Figure 5 for an illustration of a complex vibration profile in spectral terms.

Therefore, for predictive maintenance, accelerometers need to deliver three important parameters. They need to have low noise (earlier prediction), high bandwidth (to detect all spectral content and aid in the classification of the fault), and a sufficiently high measurement range. The last one is often overlooked, however, as the magnitude of acceleration is proportional to the frequency ω^2 , and high frequency spectral content can saturate the sensor if not considered. The new ADXL382 triaxial, digital accelerometer offers all three requirements in a compact package. The product has a full-scale range of up to 60 g, 8 kHz bandwidth, and ultralow noise $< 55 \mu\text{g}/\sqrt{\text{Hz}}$.

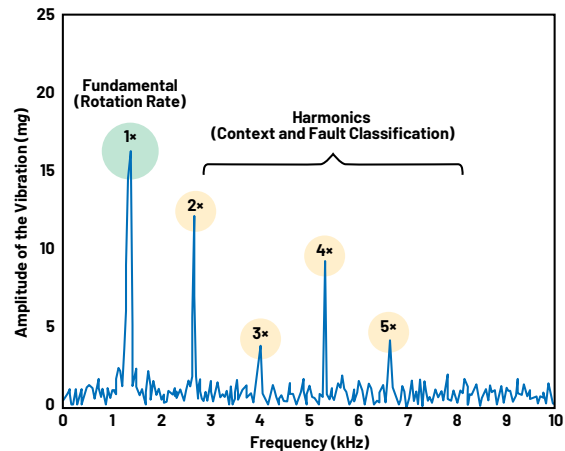


Figure 5. Wide bandwidth, spectral representation of common machine faults.

Conclusion

Automation and technology in agriculture address critical global challenges, including food security, labor shortages, and environmental sustainability. By embracing innovations such as AI, robotics, and precision farming, the agricultural sector can enhance efficiency, reduce costs, and ensure a more sustainable future for food production. Inertial sensors have a key role to play in this ecosystem since they provide enabling sense capabilities. However, care must be taken to choose sensors with appropriate fit and function.

Reference

¹"Global Agriculture Towards 2050." Food and Agriculture Organization of the United Nations, October 2009.

About the Author

Tzeno Galchev is the director of marketing and applications engineering for inertial sensing solutions at Analog Devices. In this role, he oversees ADI's business in inertial sensing, including strategic marketing, product definition, and applications engineering. He received B.S. degrees in both electrical and computer engineering in 2004, and M.S. and Ph.D. degrees in electrical engineering in 2006 and 2010, respectively, all from the University of Michigan, Ann Arbor. He has over 30 publications in MEMS and patents and is a frequent lecturer and speaker on topics related to MEMS, energy harvesting, and sensors.

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