

AI-Driven Monitoring and Fault Prevention Enabled by Advanced Industrial Communications



Introduction

Artificial Intelligence (AI) is revolutionizing how industries operate, moving beyond traditional reactive maintenance approaches to proactive, data-driven decision making. AI technologies enable systems to learn from vast amounts of operational data, identify patterns invisible to human operators, and predict future outcomes with remarkable accuracy. This transformation is particularly evident across diverse industrial applications—from autonomous vehicles and smart manufacturing to energy grid optimization and supply chain management.

One of the most impactful AI applications in industrial settings is predictive maintenance, which has become a critical priority for manufacturing plants across all industries—from oil and gas to factory automation, robotics, and energy infrastructure. Wherever motors and gearboxes drive production processes, AI-enhanced continuous health monitoring is essential to prevent unexpected failures that can halt operations. Unplanned production stoppages carry enormous costs due to lost productivity and revenue.

Traditional maintenance strategies wait for equipment to fail catastrophically as motors and gearboxes naturally wear over time. However, AI algorithms can detect early warning signs that precede breakdowns, including subtle changes in current draw, temperature variations, and vibration pattern shifts that human operators can miss. Beyond production interruptions, AI-predicted failures of large motors or turbines can prevent mechanical explosions that pose serious safety risks to personnel.

AI-powered monitoring of critical parameters—current, voltage, temperature, and vibration—enables sophisticated pattern recognition and failure prediction across the factory floor. By integrating machine learning algorithms directly into the industrial automation pyramid, plant operators can receive advance warnings of potential equipment issues with unprecedented accuracy. This allows for optimally scheduled maintenance during non-production hours, preventing costly unplanned downtime while maximizing equipment lifespan.

Industrial Communication with AI-Driven Communication and Fault Prevention Demo Setup

The demonstration system exemplifies how AI integrates seamlessly within the traditional automation pyramid architecture. At the foundation level, the system incorporates intelligent sensors and actuators, with some sensors featuring integrated AI accelerators and algorithms to reduce data transmission requirements and enable direct fault detection at the edge. Industrial communication protocols serve as the intelligent backbone, interconnecting AI-enabled sensors with gateways, PLCs, and cloud infrastructure to create a comprehensive, predictive maintenance ecosystem.

The demonstrator consists of the following sections.

- Vibration sensing demo with Edge Processing board (TIDA-010261), IEPE front-end (TIDA-010249) and Edge Gateway board (TIDA-010262)
- Industrial Ethernet
 - 100Mbit industrial Ethernet System-on-Module solution (TICS100MOD)
 - 100Mbit industrial Ethernet reference design (TIDA-010973)
- IO-Link
 - Industrial Ethernet to 8-port IO-Link Master Gateway (TIDA-011002)
 - IO-Link Device sensor/actuator (TIDA-010263)
- Vibration and imbalance detection with AM13E230x board

Vibration Sensing for Predictive Maintenance Using Edge Compute Sensor Board and AI-Enabled Gateway

Predictive maintenance represents a fundamental shift from traditional *run-to-failure* strategies to intelligent, data-driven asset management. By continuously monitoring equipment health indicators, organizations can prevent unexpected breakdowns, reduce maintenance costs by up to 30%, and extend equipment lifespan significantly. This proactive approach not only eliminates costly emergency repairs but also optimizes maintenance schedules,

reduces spare parts inventory, and most importantly, prevents safety incidents that could endanger personnel. In manufacturing environments where a single production line failure can cost thousands of dollars per hour, predictive maintenance has become essential for maintaining competitive advantage and operational efficiency.

The vibration sensing subsystem demonstrates this predictive maintenance philosophy through an integrated architecture comprising three interconnected reference designs:

- [TIDA-010262](#): Gateway reference design for data aggregation and cloud connectivity
- [TIDA-010261](#): Edge processing reference design for real-time vibration analysis
- [TIDA-010249](#): Analog front end specifically designed for IEPE vibration sensors

The **Gateway Board ([TIDA-010262](#))** serves as the central hub, featuring an AM6442 processor running Linux to manage multiple data streams simultaneously. This supports four independent T1L PHYs for sensor connectivity and includes a 1Gbit Ethernet port for seamless cloud integration. The design incorporates Power over Data Line Powered Sourcing Equipment (PoDL PSE) with SCCP negotiation capability, enabling simplified installation and reduced wiring complexity.

The **Sensor Board ([TIDA-010261](#))** operates at the edge with an AM2432 processor optimized for real-time signal processing. It features PoDL Powered Device (PD) support with SCCP negotiation for intelligent power management. The integrated TIDA-010249 analog front end can simultaneously interface with up to four IEPE (Integrated Electronics Piezo-Electric) sensors, connecting through a high-performance interface (HPI) to the AM243x processor for immediate data processing.

Communication Infrastructure leverages T1L (10BASE-T1L) single-pair Ethernet technology, providing robust data transmission over distances up to 2 kilometers using a single wire pair. Power over Data Line (PoDL) technology delivers both power and data simultaneously, dramatically simplifying installation in industrial environments while maintaining reliable communication.

Intelligent System Operation

The system operates through a sophisticated data pipeline optimized for predictive maintenance:

1. **Data Acquisition:** IEPE vibration sensors continuously capture mechanical vibration signatures from rotating machinery
2. **Signal Conditioning:** The analog front end's high-precision ADC converts analog vibration signals to digital format with exceptional fidelity
3. **Edge Processing:** The sensor board performs real-time FFT (Fast Fourier Transform) calculations, transforming vibration data from time domain to frequency domain for advanced analysis
4. **Pattern Recognition:** Frequency domain analysis reveals critical information about bearing wear, imbalance, misalignment, and other mechanical fault signatures
5. **Data Transmission:** Processed vibration spectra transmit via T1L SPE to the gateway board for comprehensive analysis and data fusion
6. **AI-Enhanced Analysis:** The gateway executes sophisticated AI algorithms that correlate vibration data with complementary parameters including motor current signatures, voltage variations, and temperature trends
7. **Cloud Integration:** Processed results and predictive insights become immediately available to enterprise cloud services for long-term trend analysis, maintenance scheduling, and fleet-wide optimization

100Mbit Industrial Communication Reference Design

The [TIDA-010973](#) reference design provides a comprehensive solution for integrating 100Mbit industrial Ethernet into the design. This platform enables multi-protocol industrial Ethernet support, including EtherCAT, Profinet, and Ethernet/IP protocols.

Key Components:

- [AM2612](#) 500MHz dual-core Arm® Cortex®-R5F-based MCU with real-time control
- [DP83826AI](#) Ethernet PHY
- [TPS65214](#) PMIC
- [LMK3C0105](#) BAW oscillator and 4-output clock buffer

The LMK3C0105 synchronizes the microcontroller with the Ethernet PHYs—critical for industrial Ethernet protocols like EtherCAT that utilize 'on-the-fly' packet processing. Shared clock sources between the MCU and PHY prevent TX buffer overflow or underrun conditions.

The reference design includes complete design files: schematics, BOM, Gerber files, and Altium design files. Both the Industrial SDK and MCU SDK for the AM261x EVM are compatible with TIDA-010973. The design guide details enhancements and modifications between TIDA-010973 and standard TI EVMs.

100Mbit Industrial Communication System on Module (TICS100MOD)

A compact, production-ready Industrial Ethernet Communication Module built based on Texas Instruments AM2612 MCU and TI PHYs, designed to support multiple certified real-time Ethernet protocols on a single hardware platform. The module enables equipment manufacturers to integrate industrial Ethernet communication simpler, and cost-efficiently, without redesigning the baseboard.

Cost Effective IO-Link Gateway Reference Design

The IO-Link gateway reference design (TIDA-011002) showcases a cost-optimized IO-Link Master evaluation board that serves as a multiprotocol industrial gateway, translating between various Industrial Ethernet protocols and IO-Link devices.

Demo Setup: The board functions as an intelligent gateway in an industrial automation scenario, seamlessly bridging the gap between high-level industrial networks (EtherCAT, Profinet, Ethernet/IP) and field-level IO-Link sensors and actuators.

Key demonstration features:

1. Multiprotocol Industrial Ethernet Connectivity
 - Live switching between EtherCAT, Profinet, and Ethernet/IP protocols
 - 10/100 Mbit network performance demonstration
 - Real-time data exchange with industrial controllers
2. 8-Port IO-Link Master Capabilities
 - Connect up to eight IO-Link devices (sensors, actuators, smart devices)
 - 1A per port power delivery demonstration
 - COM3 communication at 400µs cycle time
 - Low CPU load operation thanks to PRU-based frame handler

AM64x/AM62 AI Development Tools

TI Microprocessors like AM64, AM62, AM62P and AM62L come with software support for industry-standard AI runtimes [ONNX Runtime](#) and [Tensorflow-lite \(LiteRT\)](#). AI Models trained on servers or PC's with tools like [PyTorch](#) and [Tensorflow](#) are exported into .ONNX and .TFLITE format and used to run inference on the embedded microprocessor.

Neural networks operating on time-series data can solve many problems in industrial automation and networking, especially on a network hub or sensor aggregator device. Anomaly detection and classification models predict maintenance needs by

analyzing motor speed, vibrational patterns, audio and electrical characteristics. Time-varying patterns in network characteristics captured for individual packets, links, device-utilization and protocol-specific metrics forecast network behavior and can improve networking performance and quality of service.

The Linux SDK for these processors enables developers to run AI models on Arm Cortex™ A53 cores. For most applications of AI-based preventative maintenance using time-series data, CPU cores of this caliber are sufficient and do not require hardware acceleration, that is, an NPU. Standard implementations from [XNNPACK](#) and [ARMNN](#) provide enough performance to meet latency requirements. In this way, developers can create their AI models with industry standard tools for these devices, with zero reliance on target-specific or custom toolchains. In some cases, for example high volume or channels of data, extremely low-latency requirements or especially complex models, an NPU may be required. TI is continuing to invest this area to accelerate more challenging applications of Edge AI.

AM13E230x Motor Imbalance Detection Demonstration

This demonstration showcases how the AM13E230x device provides imbalance and fault detection in fan applications. The high-performance device leverages AI acceleration and an intuitive software ecosystem designed for home automation applications to improve performance, decrease power consumption, and overall increase the longevity of the motors used. The AM13E230x leverages its 200MHz performance capabilities along with TinyEngine™ NPU to run simultaneous motor control and AI software solutions. In smart home automation, key engineering concerns over motor longevity and fault detection are important design aspects considered in the AM13E230x.

Demo Scenario: There are two fans connected to AM13E230x hardware ecosystems (LaunchPad EVM and Gate Driver Board). One fan operates with a screw attached to one of the blades. The AM13E230x detects the resulting imbalance due to the screw on the blade. The other fan shows the fan running normally. This demonstrates how EdgeAI designs are used in fan motors to detect fan imbalances and prevent from destroying the overall motor which improves the performance.

Key Features:

- High Performance: 200MHz Arm® Cortex®-M33 processor
- AI Acceleration: TinyEngine™ NPU

- Detection Capabilities: Vibration, fault, and imbalance detection via Edge AI algorithms
- Software Ecosystem: Motor Control GUI with Zero, EdgeStudio, and software libraries accessible through Secure Resources code interface

Demo Components:

- AM13E230x LaunchPad development board
- Application notes covering EdgeAI, Motor Control GUI, and InstaSPIN
- PMSM/BLDC low-voltage fan with test screw

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