

Enabling Continuous and Reliable Process Monitoring with Wireless Vibration Sensors

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Factory automation and overall efficiency justifiably receive tremendous focus, not only for the upside benefit realizable from even small increases in output, but also from the equally important potential to reduce or eliminate the severe costs of equipment downtime. Rather than rely on advancements in the discernment of available statistical data to predict maintenance needs or simply on better trained technicians, true real-time analysis and control via advances in sensing and wireless transmission is now possible.

Precision industrial processes (see Figure 1) are increasingly reliant on efficient and consistent operation of motors and associated machinery. Imbalance, defects, loose fittings, and other anomalies in the machinery typically translate into vibration, and then loss of precision, as well as safety concerns. When these are left unaddressed, besides the performance and safety issues, loss of productivity becomes inevitable as equipment needs to be taken offline for repair. Even slight shifts in equipment performance, which are typically difficult to predict in a timely manner, quickly translate into measurable lost productivity.

Process monitoring and condition-based predictive maintenance are known and proven approaches for avoiding productivity loss, but the value of these approaches are matched by their complexity. Existing methods have limitations, particularly when it comes to analyzing the vibration data, however collected, and isolating error sources.

Typical data collection approaches include simple piezo-based sensors mounted to the machinery, and handheld data collection tools. These methods have a number of limitations, particularly when compared with the ideal solution of a complete detection and analysis system that can be embedded on or in the machinery and act autonomously. These limitations and comparisons with the ideal—an

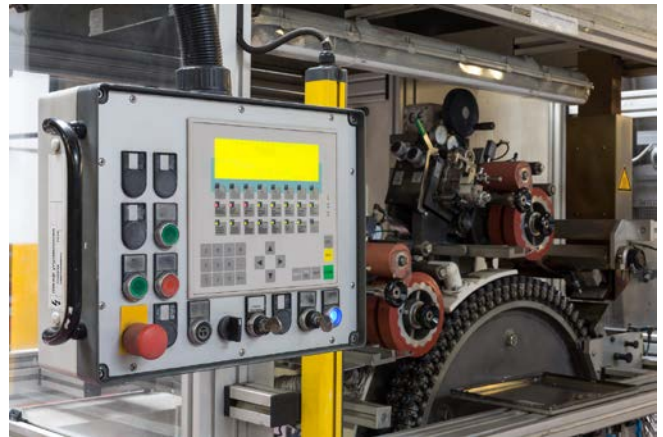


Figure 1. Automation of Process Control and Maintenance Within a Factory Setting; High Value Target for Wireless Sensing Networks

autonomous and wireless embedded sensor—are explored further here. The analysis of options towards the complex system goal of a fully embedded and autonomous sensing element can be broken into ten separate concerns, including making highly repeatable measurements, accurately assessing the captured data, and proper documentation and traceability, each of which is treated below with a discussion of available approaches vs. the ideal.

Accurate and Repeatable Measurement

Existing handheld vibration probes (see Figure 2) offer some implementation advantages, including not requiring any modification to the end equipment and the fact that they are relatively highly integrated, which, given their large (brick) size, allows sufficient processing and storage. However, one major limitation is the lack of repeatability of the measurements. Slight differences in the probe location or angle will produce inconsistent vibration profiles, making time comparisons inaccurate. Thus, the maintenance technician is left with the question of whether any observed vibration shift is due to an actual change within the machinery, or just a change in the measurement technique. Ideally, the sensor would be both compact and integrated sufficiently to allow direct and permanent embedding within the equipment of interest, thus eliminating any concerns of measurement location shift, and allowing complete flexibility in the scheduling of measurements.



Figure 2. Existing Manual Probe Methods for Equipment Vibration Shift Monitoring Lack Repeatability and Reliability

Frequency and Scheduling of Measurements

Process monitoring can be particularly valuable in a production facility for high value equipment, for instance, in the manufacturing of sensitive electronic components. In this case, subtle shifts in the assembly line may not only lead to decreases in factory output but to end equipment critical specification shifts as well. An obvious limitation of the handheld probe approach is the lack of real-time notification of troublesome vibration shifts. The same is true for most piezo-based sensors, which are typically at a very low level of integration (transducer only in some cases), with the data transferred elsewhere for later analysis. These devices require external intervention and thus present an opportunity for missed events/shifts. On the other hand, an autonomous sensor processing system, which includes sensor, analysis, storage, and alarm capability, and is still small enough for embedding, offers the fastest notification of vibration shifts, as well as the best ability to show time-based trends.

Understanding the Data

Real-time notification from an embedded sensor, discussed above, is only possible if frequency domain analysis is employed. Any given equipment typically has multiple sources of vibration (bearing defects, imbalance, gear mesh), including those sources that are by design, for instance a drill or machine press that produces vibration in its normal course of operation. A time-based analysis of the equipment produces a complex waveform, combining these multiple sources, which provides little discernible information prior to FFT analysis. Most piezo-based sensor solutions rely on external computation and analysis of the FFT. This not only eliminates the possibility of real-time notification, but it also puts substantial additional design burden on the equipment developer. With embedded FFT analysis at the sensor, vibration shifts can be isolated to specific sources immediately. Such a fully integrated sensor element could also reduce development time for equipment designers by six to 12 months, given the completeness and simplicity of a fully integrated and autonomous sensor.

Data Access and Transmission

While embedded sensing is ideal to achieve accurate and real-time trend data, this does complicate the task of transferring data to what is typically a remote process controller or operator. Embedded FFT analysis also obviously assumes that the analog sensor data has been conditioned and converted to digital to support simplified data transmission. In fact, most vibration sensor solutions in use today are analog output only, leading to signal degradation during transmission, not to mention the already discussed complexity of offline data analysis. Given that most industrial equipment requiring vibration monitoring tends to exist in noisy, moving, inaccessible, even dangerous environments, there is a strong desire not only to reduce the complexity of interface cabling but again to also perform as much of the data analysis as possible at the source to capture the most accurate representation of the equipment vibration as possible. A wirelessly enabled sensor node not only facilitates immediate access, but greatly simplifies the deployment of the sensor network, and at significantly reduced cost.

Data Directionality

Many existing sensor solutions are single axis piezo transducers. These piezo sensors provide no directionality information and, thus, limit the understanding of the equipment vibration profile. The lack of directionality translates to the need for very low noise sensors to enable the necessary discernment, which also affects cost. The availability of multi-axis MEMS-based sensors, if precision aligned across axes, allows a significant increase in the ability to isolate the vibration source, while also potentially improving cost.

Location and Distribution of Sensors

Equipment vibration profiles are complex, time shifting, and susceptible to variances based on the equipment materials and location. The question of where to place sensors is of course, critical but also highly dependent on the type of equipment, environment, and even the life cycle of the equipment. With existing high cost sensor elements limiting the number of probe points to few or one, this question is more critical. This translates to either significant additional upfront development time to determine optimal placement through experimentation, or in most cases leads to some compromise in the amount and quality of data to be captured. The existence of more fully integrated sensor probes at a fraction of existing costs can allow placement of multiple probes per system and less upfront development time/cost, or simply fewer and less costly sensors.

Adaption to Life Cycle Shifts

While a handheld monitoring system approach can perhaps be tailored to changes (periodicity, amount of data, etc.) over time, providing that same life cycle based customization in an embedded sensor requires upfront attention during the design and deployment to allow the needed tunability. The transducer element, regardless of technology, is, of course, important, but typically more critical is the sensor conditioning and processing wrapped around the transducer. The signal/sensor conditioning and processing is not only specific to the unique equipment, but also to the life cycle of the equipment. This translates to several important considerations in the design of the sensor. First, earlier analog-to-digital conversion (at the sensor head, versus off equipment) allows for configuration/tuning in-system. The ideal sensor would provide a simple programmable interface that would simplify the equipment setup through quick baseline data capturing, manipulation of filtering, programming of alarms, and experimentation with different sensor locations. With existing simple sensors, to the extent that any of this is configurable at equipment setup, some compromise in sensor settings must be made to accommodate changes in maintenance concerns over the life of the equipment. For instance, should the sensor be configured for early life, when equipment faults are less likely; or end of life, when faults are not only likely but potentially more detrimental? The preferred approach is an in-system programmable sensor that allows configurability to changes in life cycle. For instance, relatively infrequent monitoring (for lowest power consumption) during early life, followed by reconfiguration to frequent (user programmed period) monitoring once a shift (warning threshold) has been observed, in addition to the continuous monitoring for, and interrupt-driven notification of, user programmed alarm thresholds.

Identification of Performance Shifts/Trends

Adapting the sensor to changes in equipment life cycle is somewhat dependent on knowledge of a baseline equipment response. Even simple analog sensors can allow this, assuming the operator takes measurements, does the offline analysis, and stores this data offline, somehow properly tagged to the specific equipment and probe location. A preferred and less error prone approach would allow baseline FFT storage at the sensor head, thus eliminating any potential for misplaced data. The baseline data also helps with establishing alarm levels, which again would ideally be programmed directly at the sensor and, thus, in any subsequent data analysis/capture where warning or fault conditions are detected and a real-time interrupt can be generated.

Data Traceability and Documentation

Within a factory setting, a proper vibration analysis program may be monitoring tens or even hundreds of locations, whether by handheld probe or embedded sensor. Over the course of the lifetime of a given piece of equipment, this may produce the need for capturing thousands of records. The integrity of the predictive maintenance program depends on the proper mapping to location and time of the sensor collection point. For lowest risk, and the most valuable data, the sensor should have a unique serial number and the ability to time stamp the data, in addition to embedded storage.

Reliability

The above discussion highlights methods to improve existing sensor-based approaches for vibration monitoring related to process control and predictive maintenance. In that spirit of fault tolerance and monitoring, the sensor itself should be scrutinized. What if the sensor becomes faulty (performance shift) rather than the equipment? Alternatively, when operating with a fully autonomous sensor (as described as the ideal), how confident can we be that the sensor continues to work at all? With many existing transducers, such as piezo-based, this presents a serious limitation, as they have no means of providing any sort of in-system self test. There is always a lack of confidence in the consistency of data recorded over time, and in the end of life critical monitoring phase where real-time fault notification is time and cost critical (not to mention a significant safety concern), there is always a concern that the sensor could become nonfunctional. An essential requirement of a high confidence process control program is the ability to remotely self-test the transducer. Fortunately, this is possible with some MEMS based sensors. An embedded digital self-test capability thus closes the final gap on a reliable vibration monitoring system.

Analog Devices [ADIS16229](#) is an example of a fully autonomous and wireless frequency domain vibration monitor capable of all of the advantages outlined in the ten critical concerns discussed above. The ADIS16229 features embedded frequency domain processing, a 512-point real value FFT, and on-board storage providing the ability to identify and classify individual sources of vibration, monitor their changes over time, and react to programmable threshold levels. The device provides configurable spectral alarm bands and windowing options allowing analysis of the full frequency spectrum via the configuration of six bands, Alarm1 (warning threshold) and Alarm2 (fault threshold), for earlier and more accurate detection of problems. At its core is a multiaxis wide bandwidth MEMS-based sensor with configurable sample rate (up to 20 KSPS) and

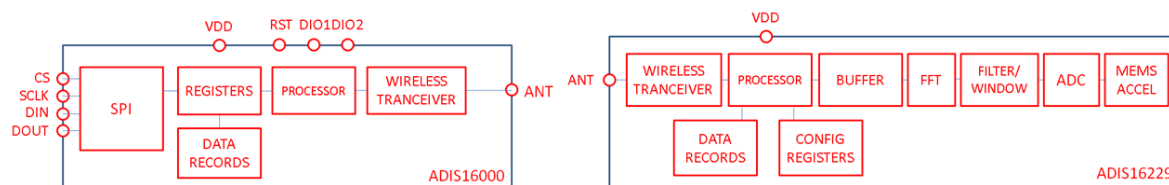


Figure 3. MEMS-Based Sensor Node (ADIS16229) with 928 MHz RF Link to Gateway Controller (ADIS16000)

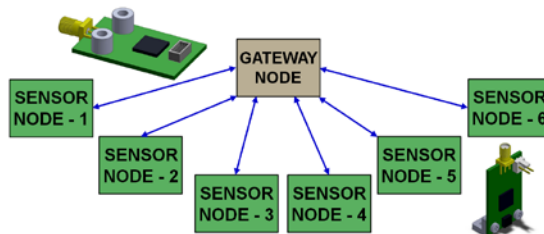


Figure 4. Six Remote Sensor Nodes Autonomously Detect/Collect/Process Data and Wirelessly Transmit to a Central Controller Node.

averaging/decimation options allowing more accurate assessment of even subtle vibration profile changes. The MEMS sensor provides a digital self-test mode to provide continuous confidence in functionality and data integrity. The device is fully embedded and programmable, enabling placement close to the vibration source and early detection of small signals in a repeatable way, avoiding data discrepancies due to differences in location/coupling from measurement to measurement, which can be the case when using handheld devices.

An 862 MHz/928 MHz proprietary wireless protocol interface allows the ADIS16229 sensor node to be remotely located, and it is supported by a separate gateway node, the ADIS16000 (see Figure 3), which provides a standard SPI interface to any system controller device. As depicted in Figure 4, up to six remote sensor nodes can be controlled via the gateway.

Fully integrated and reliable vibration sensors, with the ability for autonomous and configurable operation, provide process control and predictive maintenance program developers the ability to significantly improve the quality and integrity of the data collection process, without the limitations and compromises posed by past vibration analysis approaches. With the high level of integration, and a simplified programmable and wireless interface, these sensors can also enable a more pervasive deployment of vibration sensing by lowering the barriers to adoption of this

critical tool, which previously was limited to a handful of highly skilled technologists with decades of analytical experience in machine vibration. Such fully integrated sensors, which do not depend on retrofitted wiring/infrastructure, and which more precisely and reliably detect performance shifts, offer the opportunity for drastically reduced upfront and recurring maintenance costs.

ABOUT THE AUTHOR

Bob Scannell is a Business Development Manager for ADI's Inertial MEMS products. He has been with ADI for 18 years in various technical marketing and business development functions ranging from sensors to DSP to wireless, and previously worked at Rockwell International in both design and marketing. He holds a BS degree in electrical engineering from UCLA (University of California, Los Angeles) and an MS in computer engineering from USC (University of Southern California).

RESOURCES

ADIS16229 <http://analog.com/ADIS16229>

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