Making factories smarter, more productive through predictive maintenance

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Suppose your car could tell you when its parts are going to give you trouble, right down to the individual belt, hose, spark plug or wheel bearing.

You could get parts replaced in a few minutes on an as-needed basis before they wear out and be back on the road quickly, the same way you change a set of tires today. As a result, you could save a lot of time and expense for scheduled preventive maintenance, which replaces good parts that are in use with new ones in order to prevent parts from failing while in operation. Scheduled maintenance, with the car in the garage all day, might still be necessary on occasion, but less frequently and for far fewer parts.

Now imagine that your "vehicle" is a factory worth many times the value of a car and with many times the number of working parts. Every minute the factory spends "in the garage" for maintenance, you pay a lot of money. You follow preventive maintenance schedules to replace parts in use that might fail, but you wish there were a better way – a way to know exactly when something is going to fail – so that you could replace it just in time. Most replacements would involve relatively minor maintenance and could be performed at off times, without bringing down an entire line or the factory as a whole.

*This practice is called **predictive maintenance**. Replacing or enhancing a traditional preventive maintenance schedule with innovative predictive maintenance brings savings in parts, labor and factory down time that can repay the investment many times. Additionally, it can show which parts wear out faster and trigger rearrangement or redesigns that optimize machine use and processes.*

In the past, just-in-time predictive maintenance was largely a fantasy, but today's advanced electronics make it a reality that is rapidly increasing manufacturing productivity. Remote sensing with data transmission and aggregation, real-time communications throughout the factory, distributed control intelligence and connection to powerful data crunching and machine learning algorithms in the Internet cloud – all of these function together to monitor electromechanical systems such as motors, transport systems and robots, along with field transmitters and actuators, and give warnings of probable failures that can disrupt operations.

The same advanced electronic capabilities are changing other aspects of manufacturing, such as making production lines more flexible. One important effect is the ability to address requests of small-quantity orders, all the way down to a lot size of one for highly personalized products. But while many of these features of "smart factories" or Industry 4.0 are still to come, predictive maintenance is making its initial appearance today and can be easily installed side-by-side with existing factory control and communications systems.

Manufacturers who are looking to enable effective predictive maintenance require advanced integrated circuit (IC) solutions that cover every stage of data collection from the sensor to the cloud. Texas Instruments (TI) provides a range of innovative products designed for industrial applications, along with the expertise and commitment to bring predictive maintenance and other smart factory benefits to manufacturing plants worldwide.

Savings from predictive maintenance

Scheduled preventive maintenance is based on historic information concerning failure rates, information that usually combines tests by the equipment manufacturer with experience gained in the field for this specific machine, as well as similar machines deployed in similar environments. Typically, if a part is known to last from X to Y hours of operation, then the part is scheduled for replacement at some time well before X hours of operation have passed to provide a significant safety margin or guard band against the possibility of failure. Parts in remote or specialized equipment are sometimes changed when technicians are on site for other reasons, even though the parts might last until the next visit if their remaining useful life could be predicted. Thus, parts are replaced much earlier and more frequently than would be required if they operated until failure, wasting some of their operational life and creating additional labor and system down time. However, these costs are sacrificed in order to avoid bringing the system down because of a part failure, which could be either a nuisance or a catastrophe, depending on the circumstances.

Mechanical and electromechanical parts rarely fail without warning, though. Every car mechanic is familiar with customers who bring in their vehicles for service because “something sounds funny.” Typically, changes in voltage and current supplied to a part, in temperature, vibration, sound and other symptoms give warning that the part is nearing the end of its useful life. For example, a gas detecting sensor will change its resistance over time due to temperature and aging effects. This change can be sensed, measured and used to determine when the gas sensor needs replacement. Today’s electronic maintenance sensors are small and sensitive enough that they can pick up on these changes early and relay them through factory-area networks to data crunching centers in the cloud. There, complex algorithms can evaluate the symptoms and determine whether the part is close to failure and sometimes estimate how long it can operate safely before failing.

This determination is likely to be based on more complete statistical information than failure rates used for scheduled preventive maintenance. Instead of the hundreds or few thousands of test samples collected at product development and used to determine rates historically, cloud-based algorithms may evaluate as samples millions of parts currently in use worldwide and through their full life cycle in the field. In addition, algorithms based on multiple parameters collected from the same machine can monitor and make better-informed decisions than humans operating from limited, often imprecise information. Having more parameters may help pinpoint the problem better, too, since it may be difficult for a technician to identify exactly which part failed or is failing in a system with many parts functioning together.

Maintenance algorithms can be continually improved, both deliberately by people and automatically through machine learning. Algorithms can be partitioned when necessary so that real-time warnings or adjustments are issued by control intelligence on the factory floor at the same time that cloud-based data crunching is working on problems that are more complex and inclusive. In addition, all of this information can feed back to parts manufacturers to help improve reliability, giving factories the benefit of more robust parts with longer operational lives.

Complex data analysis may offer more options to management than simple replace-versus-not-replace decisions. With service information on good parts, as well as bad parts, and cost data for up- versus down-times throughout the factory, manufacturers can schedule combinations of preventive and predictive maintenance that are most cost-effective. Maintenance thus fits in naturally with the many other decisions that electronic sensing, communications and intelligence will enable in smart factories.

Technology requirements for predictive maintenance

The technology needed for predictive maintenance exists today and can be either designed into new production lines or retrofitted easily in existing lines. Manufacturers who are looking to implement predictive maintenance need to be aware of a number of innovative technology features that make some solutions more viable than others.

Sensors. Maintenance begins with sensing, and implementations are only as good as the sensors they employ. Temperature, vibration, noise, voltage and current are among the most common forms of sensing, but certain systems may require sensing for chemical composition, spectral analysis and/or other specialized needs.

Sensors must communicate with upstream data-gathering nodes. Since sensors are often housed in hard-to-access locations, they may not be accessible through ordinary wired connections and frequently must be capable of communicating wirelessly. The same accessibility restrictions might apply for power lines, so many sensors will require long-life battery operation or some form of energy harvesting to keep going, and will have to operate on extremely low power in order to make the most of the energy available.

Sensors include signal conversion capabilities. Like the sensing element itself, signal conversion must be sufficiently fast and granular for the application. Sensors may have to be integrated with ultra-low-power microcontrollers (MCUs), as well as communications, if some amount of processing and control is to be handled locally. For example, MCUs, and other sensor electronics, might have to provide set up and provisioning functions, sensor calibration, data aggregation and storage, data filtering or pre-processing to minimize communications and other such functions. Small spaces that are difficult to access may demand that multiple types of sensing be available in a single package. Advanced integration of widely different types of functions is the key to fulfilling these requirements.

Communications. Predictive maintenance senses, pre-processes and reports on real-time conditions, so communications have to operate with fast signaling and minimal latency, which in many applications are specified by industrial standards. The network will have to support wired and/or wireless communications to sensors and will have to provide for reporting to factory automation control centers, human operators via a human-machine interface, and the cloud. Today's industrial networks vary widely in the standards employed, and multiple protocols may be in use on the same factory floor. Predictive maintenance communications should be compatible with the more widely used standards in order to simplify implementation.

Predictive maintenance capabilities may not need to interface at all levels with an existing factory network, since they can be added on as a parallel or secondary network, with links at certain key points.

Figure 1 shows a generalized implementation of how an existing factory automation system can be retrofitted by adding a secondary network supporting predictive maintenance. The left side of the diagram represents systems on the factory floor (bottom) communicating through Industrial Ethernet to automation centers (vertical center) and then to human networks in the office (top). On the right side of the diagram, sensors in factory equipment communicate wirelessly with a gateway, which in turn communicates to the cloud. The cloud performs its data analysis algorithms, then sends results to the office network. In this case, predictive maintenance functions do not interface directly to the network on the factory floor.

This approach of a secondary predictive maintenance network has another advantage, in that it does not burden the real-time factory network with the data from the predictive maintenance sensors. Since the factory network was not designed for such high data traffic, the additional load of sensor data might cause operational difficulties.

Gateways. Sensors are typically attached to MCUs, which transmit information to gateways, possibly through data aggregation nodes along the way, depending on the size of the network. Gateways forward information that is needed for predictive maintenance decisions to the cloud, where advanced algorithms make use of it. Some functions, especially those taking place remotely in the cloud, may not be able to meet the real-time requirements of predictive maintenance. Also, there is always a danger of losing the connection to the cloud for short time periods. Therefore, local control electronics may have to be capable of initiating some actions, such as issuing warnings, and, in extreme cases, shutting down systems without waiting for decisions from the more comprehensive cloud-based services. Furthermore, when a large number of sensors are deployed, the total traffic to the cloud

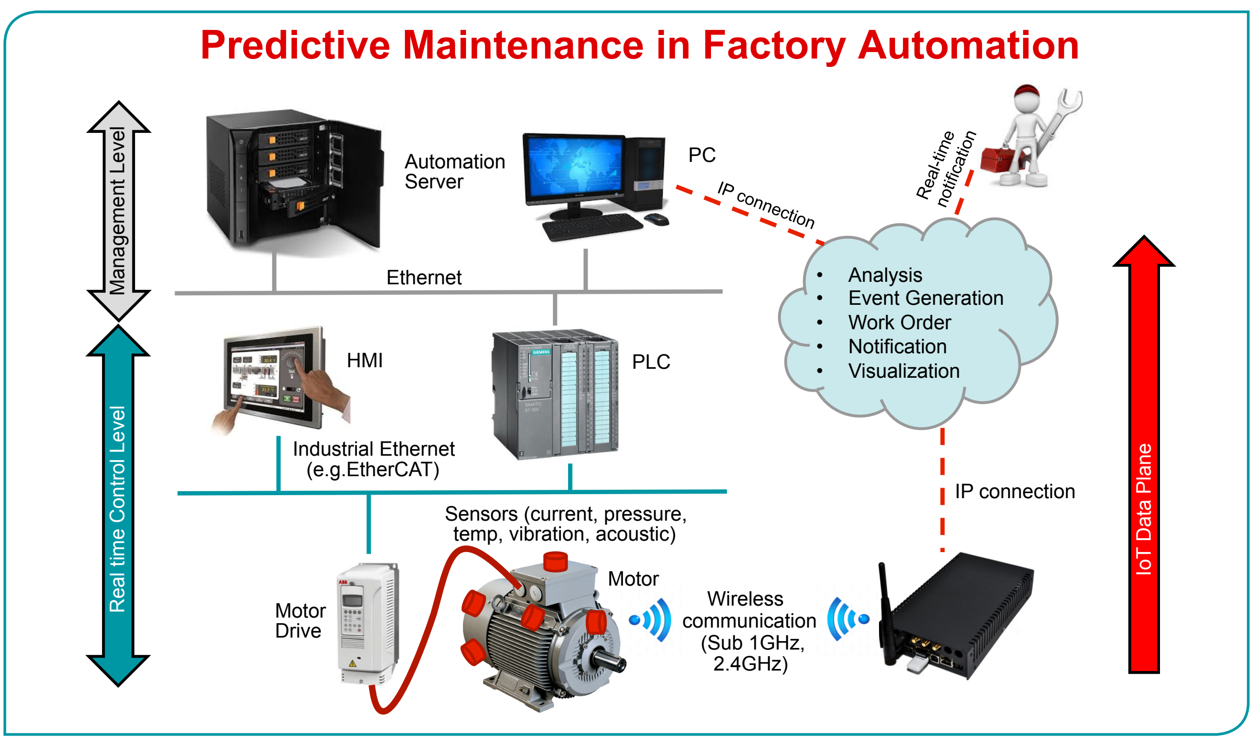

***Figure 1**. Predictive maintenance in factory automation.*

might be significant, so it might be preferable to do some pre-processing locally in the gateway to reduce the amount of data sent up to the cloud. The same gateways may perform other types of automation control as well, depending on the application.

Security. All factory networks must be secure end to end, and predictive maintenance capabilities are no exception, since there is security at every point from the sensor to the cloud. Sensors, data aggregation nodes, gateways and cloud-based systems must all be completely secure from hacking, incorporating security designed into both hardware and software. Security applies not only to the communicated data but also to the authentication of the sensor on the network.

Reliability. Industrial circuits, and sensors, especially, are subject to harsh environments that may include extremes of cold and heat, rattling, dirt, grease, vapor, chemicals and a variety of other potentially damaging conditions. Sensors and other maintenance ICs must be characterized for use under extreme conditions to ensure continued reliability on the factory floor.

Safety. Even if we use the most reliable sensors and ICs, we still have to assume that statistically some of them might fail over time. Safety is a system-level approach that ensures that no damage or harm is caused to the factory and the operators due to these failures.

Providing technology that enables predictive maintenance

Predictive maintenance demands advanced semiconductor technology across a wide spectrum of products, including sensing, sensing, signal chain, power management, MCUs with wired and wireless communication and processors (typically used in the aggregators and gateways). TI's products span the range of predictive maintenance systems from sensors to the cloud, delivering the functions, low power, reliability, security and integration required to meet the specifications of industrial applications. TI's long history of engagement with manufacturing customers and extensive involvement in industry standards mean that the company is well positioned to supply solutions that enable predictive maintenance and other applications demanded by smart factories today and in the future.

TI's advanced low-power sensors operate via wired or wireless communications, with or without local control functions, for use with batteries or energy harvesting in remote locations. Many sensing and control products integrate multiple features in a single die, such as combining a current sense amplifier and shunt monitor for more accurate, efficient motor and solenoid control. For emerging requirements, the signal chain, logic, memory and communication functions are ready for integration with sensing elements in new dedicated single- or multipurpose sensors. In addition to sensors, high-performance analog products with high integration and low-power requirements enable the creation of small systems and solutions for predictive maintenance. On-board features for signal monitoring and cyclic redundancy checks (CRCs) make it easy for system designers to meet safety and reliability requirements.

In monitoring units, data aggregation nodes and gateways, MCUs, processors and communications ICs provide the needed computing performance, storage, interfaces and communications, all with very low power consumption. These products come with built-in security features that enable end-to-end network security. MCU options include ultra-low-power devices optimized for battery-operated and energy-harvesting applications. Many of these MCUs support a variety of wired communication options.

On the other hand, wireless MCUs integrate on the same die a general-purpose MCU core coupled with a wireless communication engine supporting standards like Wi-Fi®, Bluetooth low energy (BLE), 6LoWPAN, Sub-1GHz and other wireless standards. Safety devices with core redundancy and other features provide the building blocks needed to build systems that assure maximum safety in equipment operation. Processors based on powerful ARM® cores address the needs of gateways, and some of them are equipped with digital signal processing (DSP) features to perform local pre-processing and analytics. These processors are also equipped with a communication engine supporting a variety of industrial Ethernet protocols.

Analog signal chain and monitoring functions provide checksum sampling (CSC) to ensure signal accuracy, and TI offers products with industry-specified double isolation for maximum protection of equipment and personnel in the instance of a short in a circuit or power/voltage surge. Safety versions of products are available that offer features enabling easy design of systems for functional safety for example Hercules SafeTI MCUs.

Reliable power supply is essential for all electronic systems, including sensors, gateways and other network nodes. TI's large portfolio of power management products is designed to successfully regulate battery and line power and keep circuitry operating safely, reliably and efficiently. All IC products that are used for predictive maintenance and other smart factory applications are available in versions characterized for industrial use for enhanced reliability.

Keeping factory lines moving

Effective maintenance is essential to the use of any system, from a penknife to a space probe. However, in complex industrial systems, scheduled maintenance to prevent failures entails high costs in parts, labor and down time. Today's electronics enable successful sensing, communications and decision-making for complex electromechanical systems, making possible predictive maintenance with just-in-time replacement of parts that are wearing out but not yet failing – delivering significant cost savings and greater reliability, safety and efficiency. In predictive maintenance, as in other smart factory applications, TI plays a leading role in providing innovative technology that helps manufacturers maximize productivity and better satisfy their customers.

For more information:

- Visit our Factory Automation & Control and our IoT web pages
- Check out related reference designs, including:
  - Field Transmitter with *Bluetooth*® Low Energy (BLE) from 4 to 20-mA Current Loop Reference Design
  - Single-Chip, Loop-Powered 4-20mA RTD Sensor Transmitter Reference Design
- Get information about TI's Current Sense Amplifiers and MCUs

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