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IT@Intel: Expanding Low-Cost IIoT Manufacturing Use Cases

From predicting equipment failures to optimizing material usage, Intel IT's affordable Industrial Internet of Things (IIoT) projects create significant savings and reduce factory equipment downtime

Authors

Duncan Lee
Manufacturing IT Principal Engineer, Intel IT

Barry Masterson
Manufacturing IT Engineer, Intel IT

Joe Sartini
Industry Engagement Manager
Manufacturing 4.0, Intel IT

David Schlick
Manufacturing IT Engineer, Intel IT

Boon Yee Ee
Senior Technical Lead,
Assembly and Test Manufacturing

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Executive Summary

Intel IT continues to build on our previous successes with connecting the unconnected in the factory. Our standardized Industrial Internet of Things (IIoT) infrastructure is highly scalable and has numerous business benefits:

- Scrap avoidance
- Fewer excursions
- Cost savings
- Less unscheduled downtime

We have found that IIoT, combined with machine learning and big data analytics, can be a powerful tool to help us better diagnose and perform predictive maintenance. A proactive maintenance strategy maximizes factory productivity by reducing the risk of unexpected failures that can cause product yield loss.

Our IIoT infrastructure takes advantage of Intel® IoT Gateways equipped with Intel® CPUs. The gateways enable us to use automation to connect devices and data. The result is an efficient, data-driven factory environment that embodies smart manufacturing.

This paper describes our IIoT infrastructure and the central IIoT dashboard. We share three proven use cases that we hope will inspire other manufacturers to adopt a similar approach.

Intel IT Contributor

Rob Colby, IT Principal Engineer

Acronyms

ATM	Assembly and Test Manufacturing
HFE	hydrofluoroethers
IIoT	Industrial Internet of Things

Background

Intel IT has been using a standardized Industrial Internet of Things (IIoT) infrastructure in Intel's fabrication facilities (fabs) for several years. One of our first successful IIoT use cases was to predict the failure of fan filter units so we could repair or replace the equipment before it failed, thereby reducing scrap and equipment downtime while increasing product quality.

A majority of legacy factory equipment wasn't built with the IIoT in mind, so it is not equipped with all the necessary sensors. But manufacturers need data from this equipment. The market is responding to this scenario: in 2022, market research valued the IIoT at USD 202 billion; the market is expected to grow to USD 1,829.21 billion by 2023, representing a compound annual growth rate of 24.7% from 2023 to 2032.[1]

Retrofitting old but healthy factory equipment with sensors enables us to obtain the data we need without buying new factory equipment. Our standardized IIoT infrastructure allows us to install sensors on the older factory equipment and connect them to our central systems—for as little as a few thousand dollars. Lower-cost hardware lets us quickly generate a fast return on investment (ROI).

Building on the success of use cases such as predicting the failure of fan filter units, Intel IT has invested in other IIoT use cases:

- Computer vision and analytics help detect when a chemical tank requires filling to prevent it from running dry.
- Sensors monitor condensate tool pumps for failure, preventing flooding of the factory floor.
- Real-time sensor monitoring detects improper application of chemicals to silicon wafers.
- Sensors and edge analytics help predict centrifugal pump failures.
- Potential leakage from heating and cooling systems and factory tools requires constant stewardship, which is mitigated by a mesh of sensors across factory campuses.

Similar technology can be used in factory environments beyond fabs; we are expanding our standardized IIoT infrastructure throughout Intel's Assembly and Test Manufacturing (ATM) factories.

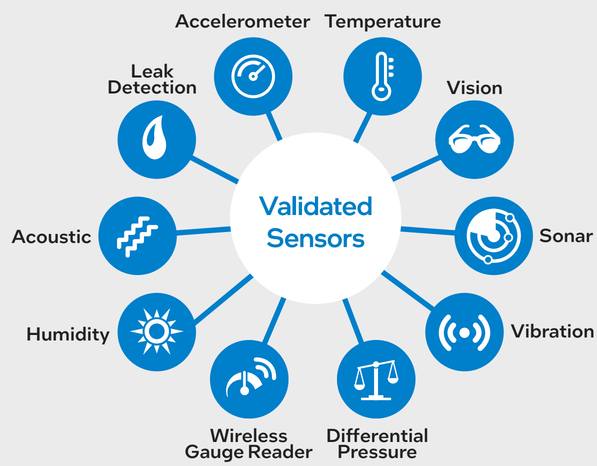
This paper describes our central IoT dashboard and discusses best practices that enable us to maximize return on investment. We explain how to implement IIoT sensors on older factory equipment that lack connectivity and how to use those sensors to collect data and enable condition monitoring and predictive maintenance. While the three use cases described here are specific to Intel's ATM facilities, similar use cases exist across various manufacturing environments. Other manufacturers can adapt our use cases and best practices to achieve similar benefits.

Increasing Solution Scalability with a Catalog of Gateways and Sensors

A standardized collection of sensors makes implementing a new use case quick and easy.

It would be time-consuming and expensive if engineers had to shop and compare sensors for a new IIoT use case. To accelerate onboarding a new use case, we pre-validate gateways and sensors and make them available to engineers via an online catalog. Our IIoT infrastructure governance does not allow one-off deployments of non-validated sensors. A firm commitment to standardization helps scale the benefits of IIoT.

We have validated one or more sensors in each of the following categories. We have sometimes validated several versions of the same sensor because some have multiple connectivity options, like Wi-Fi or USB.



[1] Source: https://www.precedenceresearch.com/iot-in-manufacturing-market

Solution Architecture

Our IIoT solution is open-source and based on Intel® architecture (see Figure 1):

- Data is collected from factory equipment using sensors. The data is collected, analyzed and formatted before being published to consuming applications. The data is sent through an Intel IoT Gateway using the message queue telemetry transport (MQTT) protocol.
- Software developers write drivers that analyze the collected data and enforce policies such as monitoring for exceeded thresholds.

This open-source solution has zero license costs and democratizes the solution—if additional factory equipment needs IIoT monitoring, an engineer can add new drivers to the library.

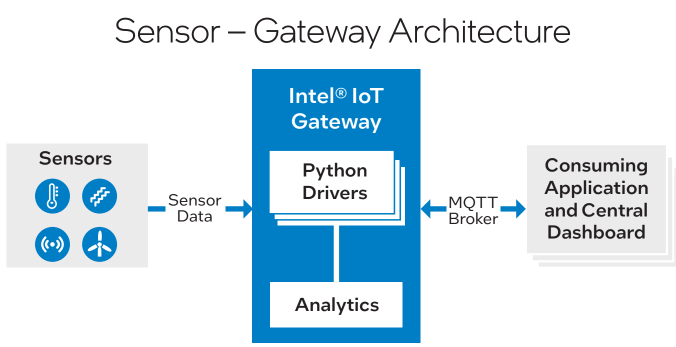


Figure 1. End-to-end architecture from IIoT sensors to a central dashboard.

AI at the Edge

We use AI/ML at the edge to sift through large volumes of data ingested from sensors to identify actionable insights. For example, for a mid-level piece of rotating equipment, we typically use two vibration sensors that are attached to a single Intel IoT-based gateway, which generate about 54,000 time-series records per second.

The data is analyzed at the edge and delivered into several processing containers. Data processing focuses on standard data collection and raw time-series data in structured or unstructured formats. Having anomaly detection at the edge allows us to intercept those events that might indicate a failure in real time. We can also use AI-based anomaly detection to compare how similar factory equipment performs at scale using AI models targeted at factory equipment planning and utilization.

Central IoT Dashboard

Our central IIoT dashboard receives the analyzed data from all the IIoT sensors in the factory. The dashboard framework applies post-edge processing to provide additional statistical values such as mean, max and standard deviation to determine when data readings stray from the accepted baseline. The received data is depicted using graphs and summary insights.

When a sensor sends data values exceeding a threshold, an alert is sent to the dashboard, and a repair ticket is automatically issued to trigger maintenance. Engineers can take the next scheduled preventive maintenance time to inspect and replace faulty components to minimize any potential impact on Intel's products. The dashboard also supports comparative trend monitoring and report generation.

Engineers have flexibility in how they access the dashboard. As needed, they can access it from industrial PCs (station controllers) or their personal laptops. The analytics engine runs in the manufacturing data center and Intel® CPUs power all PCs and servers. Depending on the sensor data and use case, the analysis process can utilize classical statistics, advanced visualization and AI.

Three Proven IIoT Use Cases

Traditional manual, reactive maintenance systems—"run to fail"—can result in extended unscheduled downtime and quality excursions. Even our current hybrid preventative maintenance approach, which uses both time and usage metrics, doesn't always prevent sudden failures or, at best, can result in wasted parts and time if the maintenance is performed prematurely.

Our vision for smart manufacturing is to create highly efficient, agile, data-driven manufacturing processes that integrate an IoT device (gateway), sensors and data analytics to achieve the following:

- Real-time monitoring
- Predictive maintenance
- Optimized production
- Quality control
- Energy efficiency
- Data analytics
- Cost reduction

The following discusses three predictive maintenance IIoT use cases that have been deployed or are in the proof-of-concept phase in Intel's ATM factories. Each use case discussion includes a high-level description of the scenario and problem, plus a summary of the results.

Predicting Pump Motor Failure

Scenario: Attaching the die to the substrate in the assembly process uses solder paste, which contains flux. The completed attachment is called a unit. When soldering is complete, the flux is washed away using distilled water in a washing machine-like tool called a deflux machine. All the completed units pass through the deflux machine post-assembly. The distilled water is extracted using multiple pumps in the deflux machine.

Problem: Pump seals, bearings and shafts can wear out over time, leading to water leakage, which causes the sensors to shut down the deflux pump. This can create several issues. For example, when the deflux machine suddenly stops, most of the units are at risk for scrap.

Solution: We deployed multiple vibration sensors for each deflux pump to enable continuous vibration monitoring to detect early marginal excess vibration signals. Figure 2 depicts the location of the vibration sensor; Figure 3 shows the IIoT dashboard, comparing healthy pump vibration data to data from a pump exhibiting excessive vibration.

Results: The vibration sensor successfully detects early signals of high vibration and sends an alert to the dashboard. Before any catastrophe or abrupt stoppage of the deflux machine occurs, we can perform preventive maintenance on the deflux machine to prevent unscheduled downtime and wasted product.

Over four years, the estimated return on investment is hundreds of thousands of dollars across several pumps. These savings result from:

- Scrap avoidance in the thousands of units.
- Noticeable electrical consumption savings (a failing pump uses more electricity than a healthy one).

Predicting Blower Failure

Scenario: For all the units processed in the factory, epoxy fills the void area between the die and the substrate to prevent shorts and solder migration.

Problem: Hardened epoxy material can jam the mechanical seals and bearings, impacting the blower's performance. Voids between the die and substrate have resulted in historical unit scraps.

Solution: Like the deflux pump solution, we attach vibration sensors to the blowers to identify signals when the blower is about to fail. Figure 4 shows the best possible placement of the sensors to detect the vibrations of the epoxy blower. Figure 5 shows the IIoT dashboard, comparing the vibration readings from before and after the blower was fixed.

Results: The sensors prevented five cases of blower failure with an estimated avoidance value to Intel in the millions.

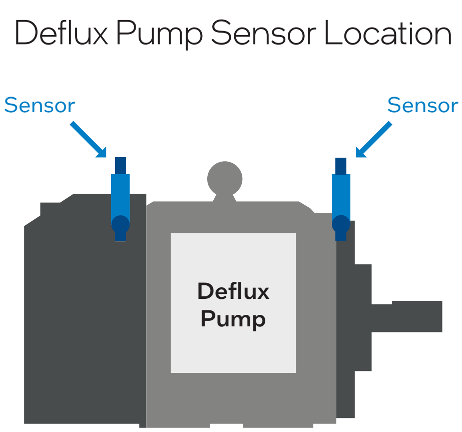


Figure 2. Placement of the pump vibration sensor.

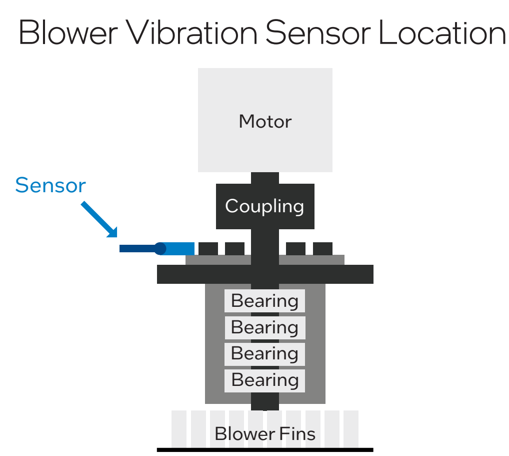


Figure 4. Placement of the blower vibration sensor.

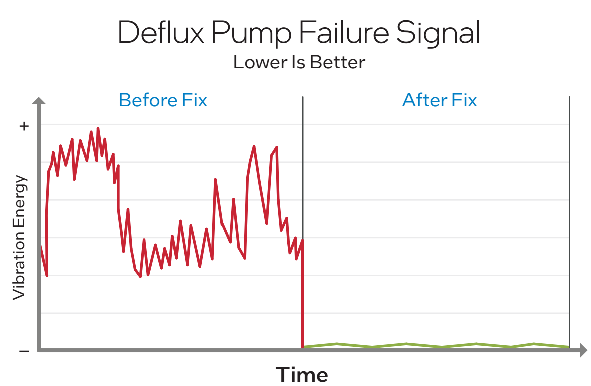


Figure 3. The IoT dashboard shows excessive vibration from a deflux pump (indicating it needs to be fixed) and the results after the pump has been fixed.

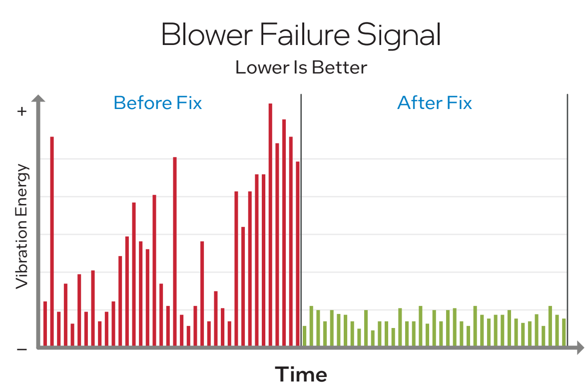


Figure 5. IoT dashboard shows excessive vibration from a blower (indicating it needs to be fixed) and the vibration signal after the blower has been fixed.

Optimizing Expensive Material Usage

Scenario: Hydrofluoroethers (HFE) are a class of non-ozone-depleting organic solvents. Some equipment in ATM facilities uses HFEs as a coolant. However, due to HFE's scarcity, they are expensive and difficult to purchase.

Problem: If a factory tool is not operating at optimal efficiency or there is a leak in the equipment, it may consume more HFE per hour than it should. There is a baseline of appropriate HFE use and wasted HFE is costly to Intel.

Solution: We deployed sensors to constantly monitor HFE flow rate. Figure 6 shows the placement of the sensor.

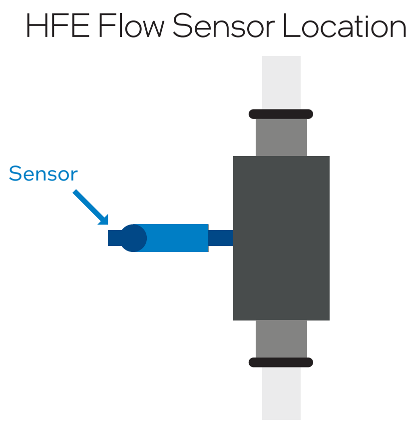


Figure 6. Placement of the HFE flow sensor.

Results: The sensors provide early detection of excessive HFE consumption caused by leaks in the HFE tubing and piping. A significant reduction in chemical waste has translated into considerable savings on material purchases.

Next Steps

We plan to deploy nine more IIoT use cases in ATM facilities in the near future. Here are some use cases:

- Laser shaft analysis to detect misalignment helps prevent blur marking on the material.
- Notifying owners of failed tools that the repair parts have arrived.
- Preventing toxic odors from affecting factory operations and people.
- Meeting state requirements for air quality.

We also plan to validate additional types of sensors, including lighting and occupancy sensors.

Guidelines for Vibration Sensors

Common Locations for Vibration Sensors

For IIoT-enabled systems to be effective, the relevant sensors must be placed in the appropriate location to detect the right signals. For monitoring the pump and motor systems, here are some of the possible locations to appropriately position the sensors to enable them to be most effective:

- **Motor housing:** Place the sensor in a location that best amplifies vibration. Attach the sensor to the motor housing near the bearing or the motor.
- **Pump housing:** Place the sensor on the pump housing, close to the mechanical seal and pump stack kit.
- **Bearing:** Mount the sensor near the bearing of both the pump and motor. Vibration in these components can indicate an issue with lubrication or wear.
- **Shaft:** Place the sensor near the mechanical seal connecting the motor and pump. This can help monitor the alignment and balance of these components.
- **Blower impeller:** Sensors that detect misalignment of the impeller and motor shaft should be placed close to the impeller.

Other Best Practices for Sensor Placement

- Check to see if the equipment has a serial or Ethernet port. Typically, ports are used by field representatives to diagnose a problem. Many serial and Ethernet port connections can output CVS-type data. If this approach is available, it typically will cost less to implement.
- Consider the overall environment where the sensors, including mounting kits and accessories, will be placed. Considerations include exposure to extreme temperatures, humidity risk and potential for liquid to spill on the sensor.
- Other items that may affect sensor placement include whether the sensor has batteries, there's a risk of outgassing or the location exposes a technician to a safety hazard.

Conclusion

Our standardized and scalable IIoT infrastructure based on Intel IoT Gateways enables the implementation of IIoT devices on various factory equipment to help address issues across Intel's factories. Predictive analysis of deflux pump and blower vibration allows us to fix equipment before it fails, which helps to avoid scrap. Early detection of HFE leakage prevents expensive chemical waste. We continue to expand our IIoT use cases and are excited about the future of smart manufacturing at Intel. We hope other manufacturers recognize the advantages of deploying a similar IIoT infrastructure and encourage them to contact Intel IT through the IT@Intel program for more information.

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