White Paper

Cyclone® V SoC FPGA

Condition-Based Maintenance: Solving Issues of the Manufacturing Industry Using Cyclone® V SoC for Edge-to-Cloud Integration

This document introduces the Vibration Analysis Condition-Based Maintenance (CBM) Service that senses the condition of equipment and facilities for preventive maintenance. The service combines Edge terminals equipped with Cyclone® V SoC FPGA with an Internet of Things (IoT) data analysis platform built on Amazon Web Services (AWS).

Macnica, Inc.

Macnica Building No. 1
1-6-3 Shin-Yokohama, Kohoku-ku,
Yokohama-shi 222–8561

https://www.macnica.co.jp/

Acroquest Technology Co., Ltd.

Tomozumi Shin-Yokohama Building 5F
3-17-2 Shin-Yokohama, Kohoku-ku,
Yokohama-shi, Kanagawa 222-0033

https://www.acroquest.co.jp/

Amazon Web Services Japan G.K.

Meguro Central Square
3-1-1 Kamiosaki, Shinagawa-ku,
Tokyo 141-0021

https://aws.amazon.com/jp/

CBM is attracting attention again
Accumulating knowledge and improving the performance of Edge terminals to reach the practical stage

CBM is gaining attention with its ability to detect anomalies or signs of anomalies through analysis of sensor data. CBM predicts the condition of equipment, facilities, and structures enabling appropriate measures to be taken for part replacement, inspection, and repair.

CBM first became popular around 2015. Listed as one of the applications in the IoT and in Industry 4.0, which is advocated in Germany, a variety of companies began working on Proofs of Concept (PoC) for it.

However, at that time, there was no knowledge about what specifications of sensors should be attached to which part of the machines and equipment, or about how to analyze data. On the other hand, many companies were concerned about the security of sending on-site data to outside the company (in the cloud). Also, it was expensive to build a server on-premises. As a result, there were many cases where PoCs were halted before proceeding to full-scale introduction.

In the subsequent few years, the environment surrounding CBM changed significantly. For example: many companies have begun to work on smart factories and digital transformation (DX); the number of experienced personnel who have managed equipment and facilities is decreasing due to retirement, etc.; due to the pandemic, there is a growing need to remotely determine the conditions of equipment and facilities; knowledge about sensing and analysis has been accumulated; Edge node performance and deep learning technology has improved; and objections to using an external Cloud is subsiding.

The greatest benefit of CBM is detecting anomalies in equipment and facilities at the predictive stage. As a result, proactive measures such as preparing and replacing parts before a failure occurs, are possible, minimizing line and plant downtime and losses.

Breakdown Maintenance (BM), which deals with failures after they occur, may take time for recover y, while Time-Based Maintenance (TBM), where inspections are scheduled at intervals of a certain period or operating time, has been criticized for its inability to predict sudden failures.

Vibration Analysis CBM service enables a small start at low cost

Among the various solutions that implement CBM, this section introduces the Vibration Analysis CBM service, which combines SENSPIDER, the edge computing terminal from Macnica Co., Ltd. (Headquarters: Kohoku- ku, Yokohama) and Torrentio Cloud, an IoT data analysis platform from Acroquest Technology Co., Ltd. (headquarters: Kohoku- ku, Yokohama). The system configuration is shown in Figure 1.

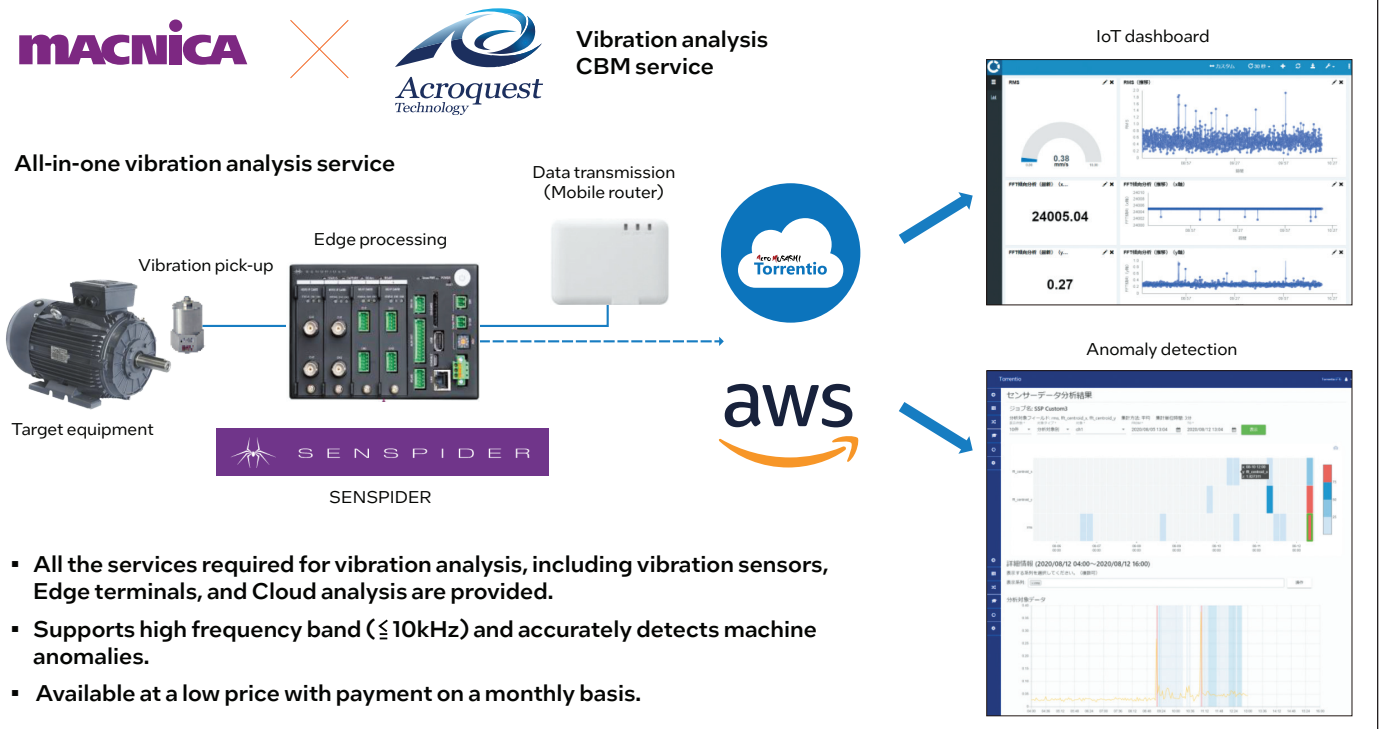
When diagnosing motor wear or failure, first, a wideband vibration sensor with a bandwidth of about 10kHz is installed at an appropriate location in the equipment or facilities. The output of the vibration sensor is sampled and signal processed by SENSPIDER, and the data is uploaded to Torrentio Cloud, which is built on Amazon Web services (AWS). The data is then analyzed by a unique algorithm developed by Acroquest Technology, and the tendencies of changes and symptoms of anomalies are displayed on the dashboard screen.

If the sensor output was sent to the cloud as raw data, not only would the amount of data be enormous, but it would also still include various noise components; thus, proper processing would not be possible. Therefore, using SENSPIDER to thin out the data, remove noise, and extract features, etc. leads to appropriate processing in Torrentio Cloud.

Depending on the sensing target and how the detection logic is configured, it is possible to detect anomalies in dynamic parts such as bearing scratches and wear, ball screw failures, spindle anomalies, tool anomalies, and shaft imbalances. Supported equipment and facilities include machiner y equipment, presses, injection molding machines, semiconductor manufacturing equipment, printing machines, boilers and compressors, conveyors, etc.

Both SENSPIDER and Torrentio Cloud are proven solutions also characterized by their low cost and Scalability. And using AWS, a solution can be scaled up to a large-scale CBM for a large variety of equipment and facilities. The next section introduces the SENSPIDER and Torrentio Cloud solutions in detail.

Figure 1. Schematic configuration of "Vibration Analysis CBM service,"combining Macnica's "SENSPIDER" edge computing terminal with Acroquest Technology's "Torrentio Cloud" IoT data analysis platform



- **All the services required for vibration analysis, including vibration sensors, Edge terminals, and Cloud analysis are provided.**
- **Supports high frequency band (≦10kHz) and accurately detects machine anomalies.**
- **Available at a low price with payment on a monthly basis.**

Fast sampling of sensor output with FPGA Feature extraction is also possible with software on ARM

SENSPIDER is an Edge computing terminal developed by Macnica. Compact, with a width of 150mm, a height of 100mm, and a depth of 85mm, it can be easily accommodated in a Control Panel and does not get in the way when directly incorporated into equipment or facilities. It consumes up to 60W and operates without a Fan (Figure 2).

There are 4 I/O slots available. Depending on the Application, it is possible to implement in combination with different configurations such as a 2-channel " fast vibration sensor interface card " to support wideband vibration sensors, a 2-channel "general purpose sensor interface card" to support voltage and current sensor, or a 2-channel "temperature sensor interface card" to which a thermocouple or thermistor can be connected. Input Signal sampling is as fast as 48kHz/16bit, enabling wideband sensing.

At the hear t of SENSPIDER is a high-performance Cyclone® V SoC FPGA that integrates a dual core Arm Cor tex-A9 MPCore processor with a large logic element (FPGA).

Since the performance will be insufficient if the sampling processing and signal processing of the sensor input of 8 channels is executed by software, SENSPIDER executes at high speed via the hardware logic implemented on the FPGA. On the other hand, more complex signal processing and network protocol processing are implemented as software on the Arm Cortex-A9 MPCore processor.

This flexible and optimal division of functions is one of the advantages of using Cyclone® V SoC FPGAs. In addition, Cyclone® V SoC FPGAs have a proven track record of long-term supply, making them ideal for industrial Edge nodes such as SENSPIDER, which require long-term operation.

SENSPIDER comes with a high-speed vibration sensor interface card. According to Macnica's evaluations, a vibration sensor band of about 1kHz is sufficient to detect vibrations caused by misalignment. However, it is necessary y to use a vibration sensor with a band of about 10kHz to detect bearing scratches, abnormal noise during operation, gear anomalies, and hydraulic cavitation, etc. (Figure 3). That is why the input sampling rate of SENSPIDER is set to a maximum of 48kHz. For a vibration sensor, Macnica recommends the 10-kHz band ultra-compact vibration pickup "VP-8021A" provided by IMV Co., Ltd. (headquarters: Nishiyodogawa Ward, Osaka City) equipped with Analog Devices' MEMS acceleration sensor "ADXL1002".

Figure 2. Schematic specifications of Macnica' s Edge computing terminal "SENSPIDER" configured with Cyclone® V SoC FPGA

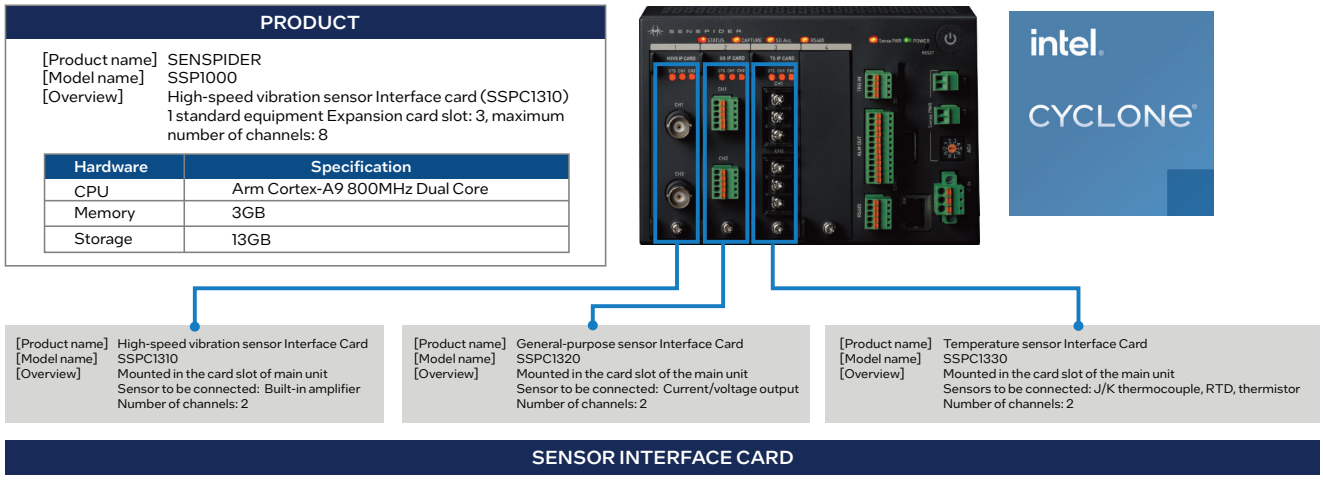
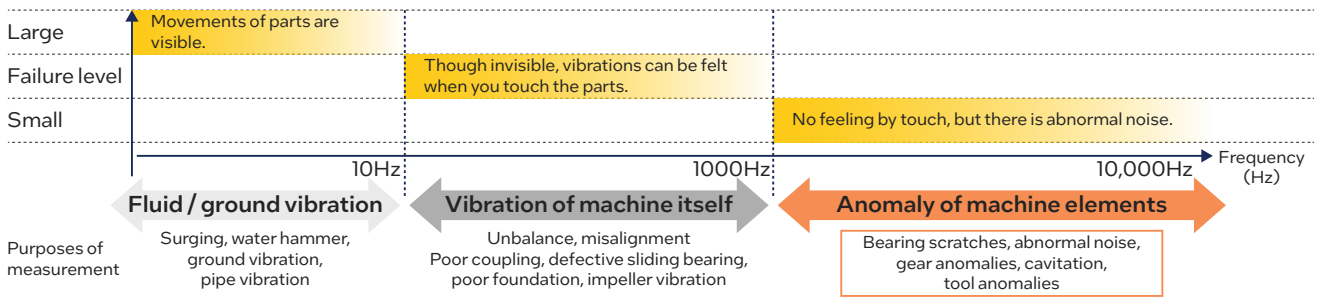


Figure 3. Rough frequency band of vibration caused by anomalies (based on Macnica research)



In SENSPIDER, in addition to sampling thinning (data extraction) for the purpose of reducing the amount of data, feature extraction by signal processing such as offset adjustment, FFT, bandpass filter, and RMS value calculation is possible. Furthermore, Macnica provides a complimentary development kit “SENSPIDER Developers Package” that implements user-specific edge processing programs and analysis algorithms based on Python, so signal processing (feature extraction) can be customized and inference processing can also capture signs of anomalies in real time.

Build inference models with unsupervised learning
Start of operation is possible in 1 to 3 months

An important par t of the Vibration Analysis CBM service is Torrentio Cloud, an IoT data analysis platform provided by Acroquest Technology. The time-series data sent from SENSPIDER is used to detect anomalies using the company's original rule control engine and hybrid predictive detection engine.

There are four types of detection patterns provided: "outlier detection" to detect data deviation; "change point detection" to detect large changes in data; "abnormal pattern detection" to detect anomalies from periodic data; and "correlation analysis" that detects anomalies from the correlation of multiple data system columns (Figure 4).

In addition, since time-series data is stored in cloud storage configured on AWS, it is possible to detect changes over a long term, which extends the functionality of SENSPIDER as a standalone component.

The challenges of CBM include data collection and learning in the event of an anomaly. Because equipment and facilities are basically operating in a normal state, data that would lead to anomalies is rarely sensed. That means it is difficult to learn. Therefore, Torrentio Cloud uses "unsupervised learning" to build a model. One of the characteristics of Torrentio Cloud is that it takes only one to three months from the start of considering CBM to the start of operation, which is less than half of time compared to the conventional method (Figure 5).

Figure 4. Four types of detection algorithms provided by Acroquest Technology's IoT data analysis platform “Torrentio Cloud”

Torrentio's predictive anomaly detection AI engine automatically determines the following trends as anomalies. These cover the typical trends that are treated as anomalies in time series data.

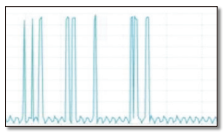
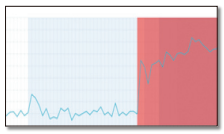
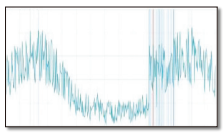
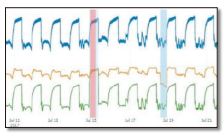
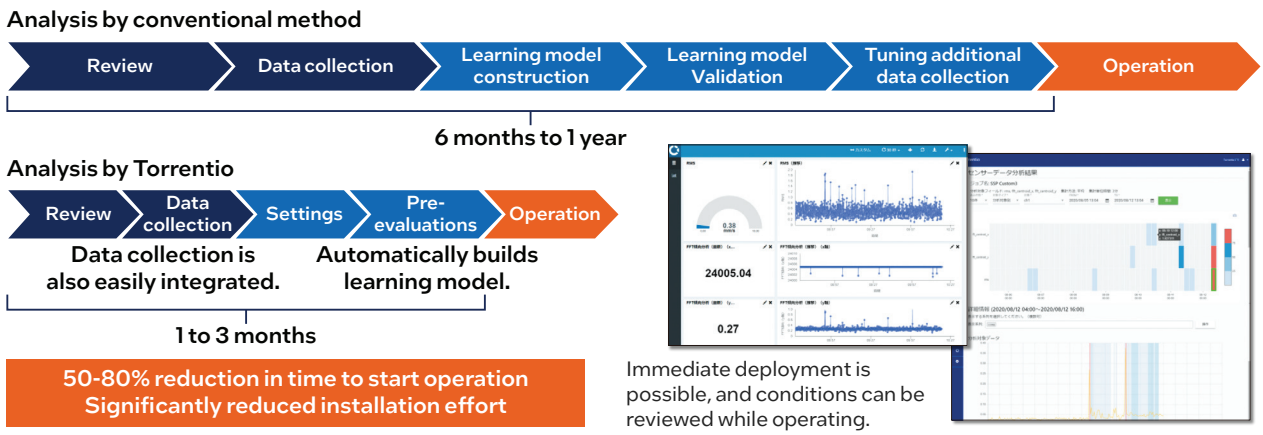
Outlier detection		It detects trends that deviate from trends that the data can usually take. It is possible to handle cases that are difficult to make simple judgments about, such as when the operating conditions differ between day and night.
Change point detection		It detects the trends where measurement data changes suddenly at some point. It also identifies situations that differ greatly from the trends of previous data.
Abnormal pattern detection		It detects discrepancies from the regular trends that can be found in the cycle when the content has periodicity and operates normally. It is effective for detecting anomalies in data with a trend that cannot be judged by the threshold values.
Correlation anomaly detection		It detects trends that deviate from trends that the data can usually take. It is possible to handle cases that are difficult to make simple judgments about, such as when the operating conditions differ between day and night.

Figure 5. Short-term model building using unsupervised learning in Torrentio Cloud



There are no particular restrictions on the amount of data that can be passed from SENSPIDER to Torrentio Cloud. However, the general usage is to reduce the amount of data by thinning out data and extracting features on the SENSPIDER side, depending on the bandwidth of the network used, the maximum monthly data volume when sending the data via public networks (SIM), the Cloud storage capacity provided on AWS, the period that the time-series data will be stored, and the division of roles for anomaly detection between SENSPIDER and Torrentio Cloud.

Optimal cloud service for building IoT systems end-to-end from Edge to outcome

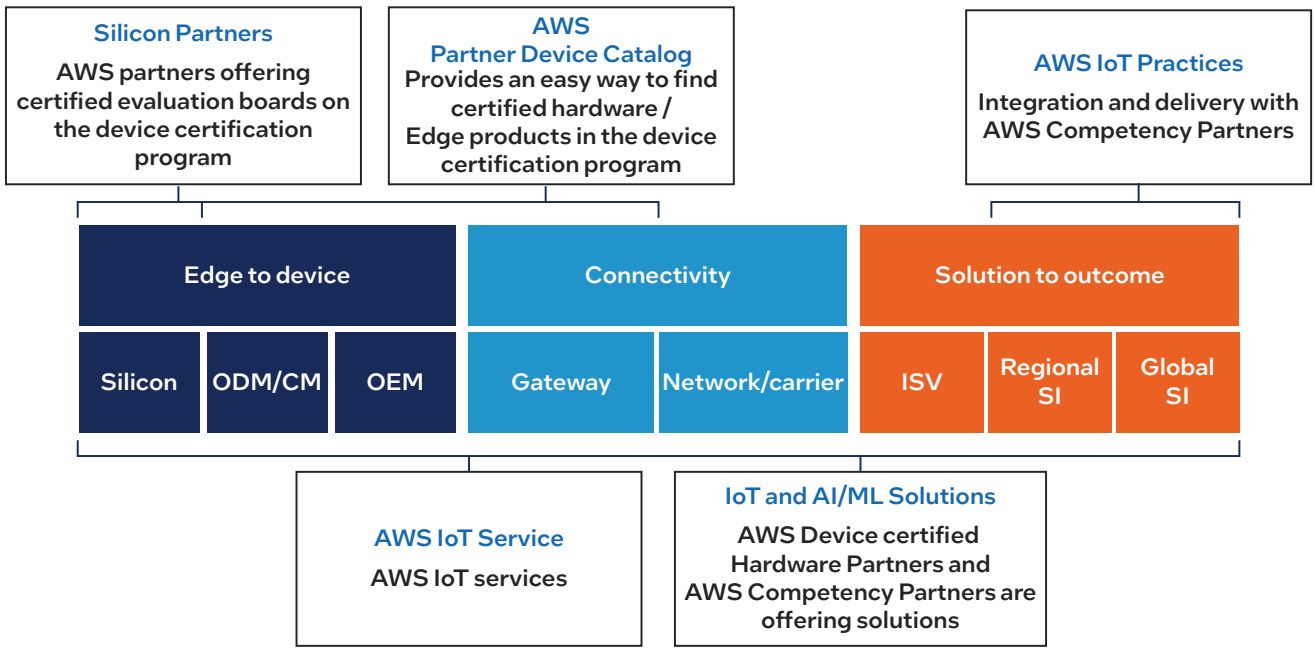
When building an IoT system, such as for preventive maintenance, it is important to select a cloud that is suitable for IoT with functions such as data collection, device management, and analysis, instead of an enterprise-oriented cloud service.

Star ting with a PoC, it would be desirable to utilize a cloud service that can build an IoT easily in a short period of time, and at low cost, in order to repeat trials agilely and finally to smoothly proceed to production operation.

Torrentio Cloud uses the AWS IoT services provided by Amazon Web Services. The features of AWS IoT services consist of a set of software that supports the construction of Edge devices, a set of services that support the control and management of Edge devices, and a set of services that analyzes data and are optimized for IoT systems.

AWS uses the phrase “Edge to Outcome” (outcome meaning achievement) to promote the value of AWS IoT (Figure 6). The concept represents the idea of providing total end-to-end support from Edge devices including silicon chips, such as processors, to integration and analysis, through network connectivity. To realize Edge to Outcome, an ecosystem is being built by partner companies, including Macnica and Acroquest Technology.

Figure 6. AWS IoT solutions that support IoT systems with Edge to Outcome



CBM that minimizes downtime and loss and also facilitates conversion from product sales to service sales

he actual implementation of the Vibration Analysis CBM service can take many forms. The most common example would be where a factor y or company with a plant installs the solution on existing equipment and facilities. Combined with smart factor y and digital transformation initiatives, it makes it possible to visualize company operations and accumulate operational know-how in-house.

Conceivably, a line builder (the factor y version of a system integrator) who is in charge of building and designing a production line could provide a vibration analysis CBM service to companies as its own service. By creating a service menu in the form of a subscription, such as a monthly fee system, steady sales can be expected, and the line operator ' s deployment and operation costs can be cur tailed at the same time.

Another possibility is for manufacturers of equipment and facilities to incorporate vibration analysis CBM services into their products. In addition to understanding the actual usage and operating conditions at the customer' s site, it is possible to provide maintenance services for equipment and facilities as added value.

* Please refer to the links below for details on each solution.

Macnica's Edge computing terminal "SENSPIDER"
https://www.macnica.co.jp/business/ai_iot/products/hardware/senspider/

Acroquest Technology's IoT data analysis platform “Torrentio Cloud“
https://www.site.torrentio.tech/torrentio/

Cyclone® V FPGA & SoC FPGA
https://www.intel.co.jp/content/www/jp/ja/products/details/fpga/cyclone/v.html

Amazon Web Services
https://aws.amazon.com/jp/

Malfunctions or failures of equipment and facilities that make up a factor y or plant may not only cause quality defects and production stoppages, and thereby great losses, but they may also threaten the safety of workers. It is desirable to establish highly effective maintenance methods by combining conventional Time-Based Maintenance (TBM) with CBM to minimize downtime and losses.

In the practice of CBM, front-end processing and feature extraction of sensors are executed on a high-performance Edge terminal, and data analysis including long-term fluctuations is per formed in the Cloud, where abundant computing resources can be provided. For this reason, Edge-to-Cloud integration is recommended. Therefore, introduction of a proven solution with low investment cost and the ability to start small and scale up, such as the Vibration Analysis CBM service from Macnica and Acroquest Technology, can help.

With the spread of CBM through Edge-to-Cloud linking, Intel will continue to meet the demands for Edge computing systems that require higher performance and sophistication by providing high-performance Intel® processors and Intel® FPGAs. In addition, we will also continue deepening our collaboration with AWS as an ecosystem partner, and support Edge-to-Cloud collaboration throughout this ecosystem.

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3-1-1 Marunouchi, Chiyoda - ku , Tokyo 100-0005
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