# Anomaly Detection using Vibration Analysis with Machine Learning Technology for Industrial IoT System

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Following the spread of IoT (Internet of Things) aimed at the utilization of factory data, industrial customers' need for anomaly/precursor detection that ties efficient site data collection with further improvements in equipment maintenance efficiency is expanding.

Against the background of worker shortage and skill inheritance, there are many customer needs to automate the sensory tests that have relied on human senses to detect anomalies.

OKI is driving an "anomaly detection" effort using a proprietary vibration analysis algorithm that utilizes machine learning, and it has released an evaluation kit for verifying whether anomaly can be detected using the algorithm. Furthermore, demonstration experiments to automate the decision of motor shipments, detect cracks in molds, and detect anomalies in machine tool ball screws have been conducted using the evaluation kit.

This article introduces OKI's efforts to monitor equipment at factories using vibration analysis.

## Expanding Need for Anomaly Detection

According to the Monodzukuri Hakusho (White Paper on Manufacturing Industries) 2017 issued by Japan's Ministry of Economy, Trade and Industry, securing human resources for leveraging the Japanese industries' strength to maintain/improve on-site capabilities and business transformation toward the creation/maximization of added value are recognized as major issues. To address the issues, the use of digital tools is gaining attention, and as of 2017, 66.6% of Japan's domestic factories are collecting some kind of site data. Unfortunately, the data is not yet being applied to any specific solutions[1].

Additionally, the vintage (age) of factory equipment has been rising from the 1990's to the present requiring further refinement in the maintenance of the aging equipment to improve the operation rate and maintain/improve quality[2].

Affected by the recent high interest in IoT, customers' need to place various sensors on factory equipment for continuous monitoring of equipment condition and detect anomalies is increasing.

## Two Approaches to Equipment Condition Monitoring

Condition monitoring is largely divided into "anomaly detection" and "anomaly diagnosis."

"Anomaly detection" mechanism notices occurrence of equipment anomaly by detecting that the equipment is "different from usual." It makes early detection of difficult to notice anomalies such as those sensed only by experienced workers.

"Anomaly diagnosis" mechanism identifies in advance the cause of equipment anomaly and the equipment condition at that time. Then, it monitors for recurrence of that condition. When an anomaly occurs, the cause is quickly isolated and recovery action is taken.

## "Anomaly Detection" using Advanced Analysis Technologies

Similar to anomaly diagnosis, "anomaly detection" mechanism monitors various sensor data and equipment logs for quickly detecting conditions that differ from normal. One of the anomaly detection methods is called the sensory test, and it utilizes human perception. This test method makes use of sounds and vibrations. Experienced workers can detect subtle anomalies in vibrations by touch and hear unusual operation sounds from the equipment with his ears.

Sensory test has many problems including lack of experienced workers, time-consuming to educate, and variations in judgment with different workers. Therefore, application of advanced analysis technologies such as machine learning is conceived for automating the sensory test.

## "Anomaly Diagnosis" using Various Monitoring Technologies

In "anomaly diagnosis," control signals, error logs, temperature, current, voltage, torque and vibrations of the equipment are monitored, and these are combined to pinpoint various anomaly locations and phenomena.

For equipment with specific structures, JIS and ISO have established guidelines for equipment anomaly diagnosis. Based on these guidelines, anomaly locations and phenomena are identified. Anomaly diagnosis using vibrations is applied to motors, pumps and bearings.

## OKI's Proprietary Vibration Analysis Algorithm

OKI is developing a proprietary vibration analysis algorithm using machine learning. The algorithm is for analyzing the high frequency vibrations close to sounds perceived by human ears in a responsive manner, and its use in automating the sensory test is highly anticipated.

The algorithm was originally an acoustic analysis technology developed for the hammering test of structures (acoustic inspection of structures such as a tunnel) in the social infrastructure market. Using NMF (Non-negative Matrix Factorization) to feature extract the frequency generation pattern of vibration data, one-class SVM machine learning was combined to improve the accuracy and performance of anomaly detection[3].

OKI has developed and has begun sales of a "Vibration Anomaly Detection Evaluation Kit" that incorporates the aforementioned algorithm for detecting anomalies in equipment. The evaluation kit is software that learns the vibration data of the equipment in normal condition as a reference and then displays the degree of deviation from the reference as a score on the screen in real-time.

The evaluation kit is designed to enable applicability verification of OKI's vibration analysis algorithm according to the following steps timed with the customer's periodic maintenance.

1) Collect vibration data from equipment in bad condition.
Collect vibration data as problematic abnormal condition from equipment just before periodic maintenance and save as a file.

2) Collect vibration data from equipment in good condition.
Perform appropriate periodic maintenance, collect vibration data as recovered normal condition and save as a file.

3) Learn vibration data from equipment in good condition.
Learn the normal vibration data collected in 2) above as a reference.

4) Identify abnormal condition.
Compare the reference value learned in 3) with the vibration data of the abnormal condition collected in 1) and confirm the degree of deviation (score) from the reference value.

**Figure 1. Applicability Verification Steps**

The score obtained in 4) after following the steps in **Figure 1** is confirmed. If the abnormal condition can be identified, OKI's vibration analysis algorithm can be applied as a mechanism for anomaly detection. The next step is systematization according to customer demand.

## Utilization of OKI's Vibration Analysis Algorithm

OKI's vibration analysis algorithm is expected for utilization in various industrial applications including the sensory test.

For equipment manufacturers, incorporating the anomaly detection mechanism using the algorithm into the company's maintenance service contract and timely resolving the equipment anomaly that occurs at the factory site will lead to maintenance service that prevents decrease in operation rate.

For end users, if the mechanism is introduced in their own companies to detect anomalies of factory equipment, they will be able to notice direct effect such as maintained/improved equipment operation rates and reduced unnecessary/unurgent maintenance costs.

The utilizations of the algorithm are introduced below through examples of demonstration experiments.

### (1) Shipment Decision of Motors

This is an example of a shipping inspection, which is the final process of motor manufacturing. In this process, the inspection is conducted with a sensory test using vibrations (sounds). However, training inspection staffs and reducing stress have been issues. Therefore, construction of an anomaly detection mechanism using vibrations is being considered to automate the sensory test.

In the mechanism, a vibration sensor is attached to the motor. The motor is spun for a few seconds on a trial basis, and from the vibrations, shipment decision is made (**Figure 2**).

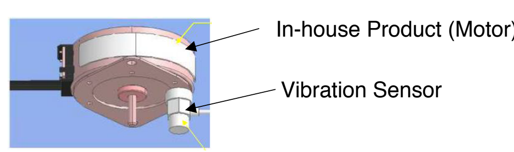


**Figure 2. Shipment Decision of Motors using Vibrations**

In the shipment inspection, it is known that largely four vibration patterns can be obtained from the normal and abnormal products. Vibrations obtained from normal products are large and small in amplitude. The same is true for abnormal products, but the differences in wave amplitudes are larger than the vibrations obtained from normal products. Although performing anomaly detection with a set amplitude threshold is common, it faces the problem of not being able to distinguish between an abnormal product with small amplitude and a normal product with large amplitude (**Figure 3**).

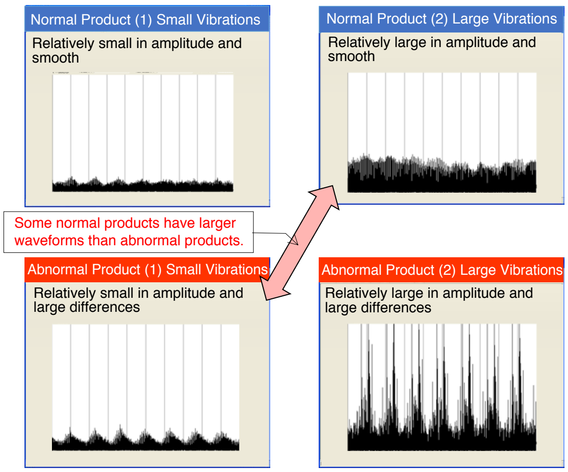


**Figure 3. Vibration Data of Normal/Abnormal Motors**

Therefore, OKI's proprietary vibration analysis algorithm was combined to handle patterns that cannot be distinguished using the common decision method. It was found that with the use of the algorithm it is possible to distinguish normal products from abnormal products regardless of vibration amplitude (**Figure 4**).

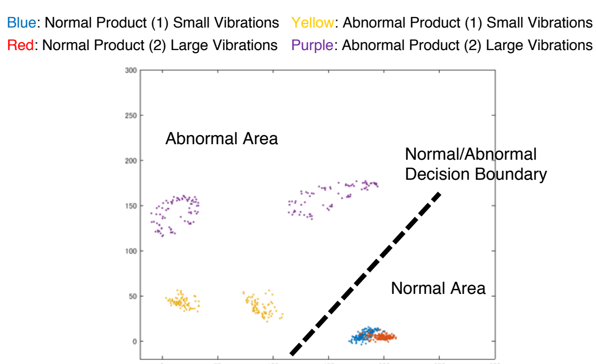


**Figure 4. Decision based on OKI's Vibration Analysis Algorithm**

Although this example is a demonstration experiment using the evaluation kit and verification with more data sets is necessary, systematization is already underway towards automating the sensory test.

**(2) Detecting Cracks in Molds**

This is an example of detecting cracks in molds used for presswork. When a crack occurs due to wear or deterioration of the mold, the required machining precision cannot be obtained and leads to the generation of defective products. In addition, if presswork is continued without noticing the crack, it is possible fragments may fly about causing injury to the operator.

Although large cracks can be confirmed with visual inspections, minute cracks are difficult to ascertain visually, and presswork may go on without the cracks being noticed. This has been a problem faced at the site (**Figure 5**).


**Figure 5. Crack in Press Mold**

Therefore, a sound collecting microphone was attached to a metal rod and a mechanism was built to detect the presence or absence of cracks by hitting the molds.

Using several sample molds, verification of anomaly detection using OKI's proprietary vibration analysis algorithm was performed. With respect to the three conditions of new, small scratches and cracked, it was found that more than 90% of the anomalies can be detected (**Figure 6**).

**Figure 6. Metal Rod and Microphone used in Crack Test**

In addition to verification with more data, study has begun for application to specific operations.

**(3) Detecting Anomalies in Machine Tool Ball Screws**

This is an example of detecting abnormal vibrations due to wear or poor maintenance of ball screws used in machine tools. Ball screw is a mechanism used in many machine tools, and it is important for positioning the machining head. If wear, scratches or rust adhesions occur to the ball screw, machining precision will deteriorate leading to defective products (**Figure 7**).

When abnormality occurs to the ball screw, it often causes high frequency vibrations (abnormal sounds). Since these vibrations sound like abnormal noise to human ears, many factories conduct sensory tests.

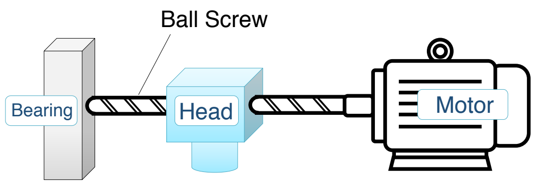


**Figure 7. General Ball Screw Mechanism**

Currently, correlation analysis between the punching process and ball screw vibration using OKI's proprietary vibration analysis algorithm is under study. The goal is to devise a mechanism that constantly monitors the ball screw vibration during punching and sends out a warning if abnormal vibrations likely to affect machining precision are detected (**Figure 8**).

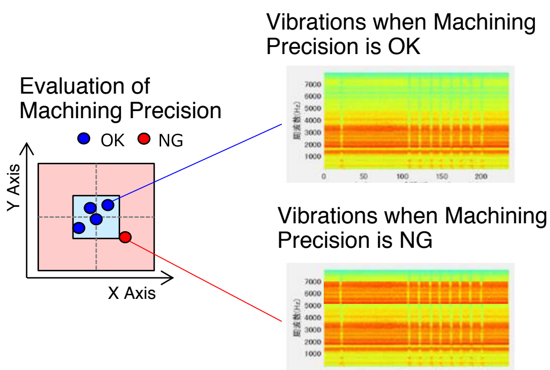


**Figure 8. Correlation between Machining Precision and Vibration**

Technical challenges are high with this example and verification of sufficient detection accuracy is a future task. However, specific methods of incorporation into equipment, such as sensor placement and cable wiring method are proceeding.

## Prospects for OKI's Vibration Analysis Algorithm

Validity of OKI's vibration analysis algorithm for use in anomaly detection has been confirmed with several applications. Other industrial applications that the algorithm can be applied to, in which sensor tests carried out by experienced workers are representative examples, will likely emerge.

The algorithm's application outside the industrial usage is also a possibility. In the maintenance of social infrastructures such as bridges, steel towers, tunnels and manholes, anomaly detection is conducted using sounds and vibrations, and as with the manufacturing industry, there is expectation for automation due to labor shortage.

While industrial applications remain the primary target, deployment to the maintenance of social infrastructures will also be kept in mind as OKI's proprietary vibration analysis algorithm is continuously upgraded for future development of technologies and solutions. ◆◆

## References


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