International Symposium: Risk–based Management of Energy Infrastructure　Tohoku Forum for Creativity
Session 2: Advanced Maintenance

Development and evaluation of an anomaly detection system using System Invariant Analysis Technology(SIAT) for sound data

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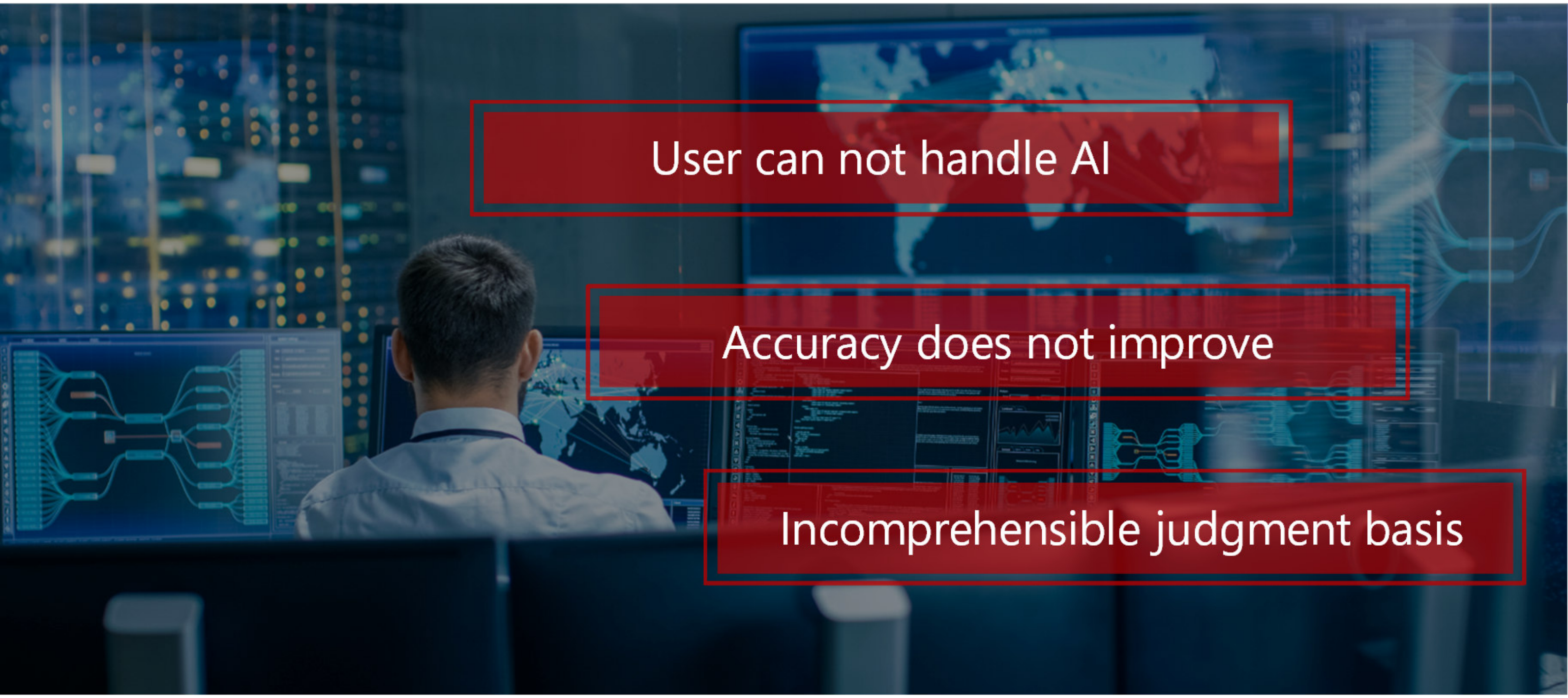
01

Challenges faced in introducing AI

Challenges in utilizing AI at equipment maintenance sites

Growing interest in AI, but manufacturing companies are facing challenges to realize utilization of AI on-site



Voices often heard in field

- ✓ Lack of human resources who handles AI
- ✓ No data scientist
- ✓ Take time to maintain accuracy of AI
- ✓ User can't understand the reason why AI judged anomaly

Important points in introducing AI

Point is that AI efforts can be maximized by focusing on the field

Is it highly accurate?

Quickly and accurately find state changes from large amounts of complex data

Is the result easy to understand?

Provide users with the basis of anomaly judgement
Highly explainable AI

Can user operate AI?

Easy to use, user can take initiative in tuning

Benefits

- ✓ Current On-site data can be handled
- ✓ Statistics and IT expertise is not required
- ✓ No need to change your organization or operations

Section

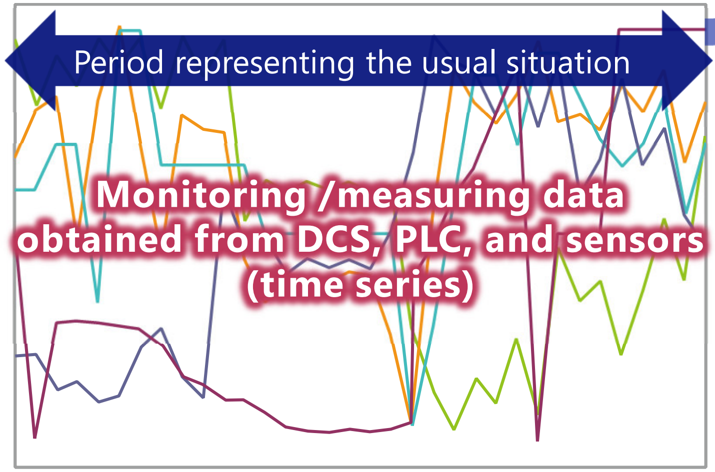
02

Overview of SIAT

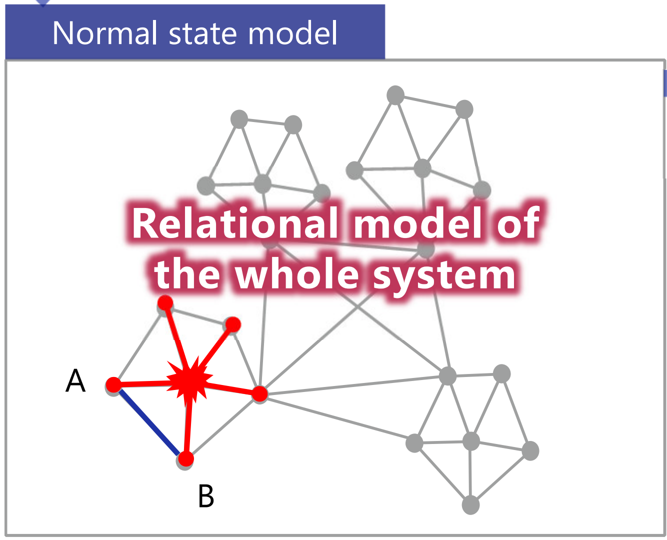
SIAT: System Invariant Analysis Technology

Overview of System Invariant Analysis Technology(SIAT)

This technology focuses on the relationships between sensors and detects abnormal behaviors very early and with high accuracy



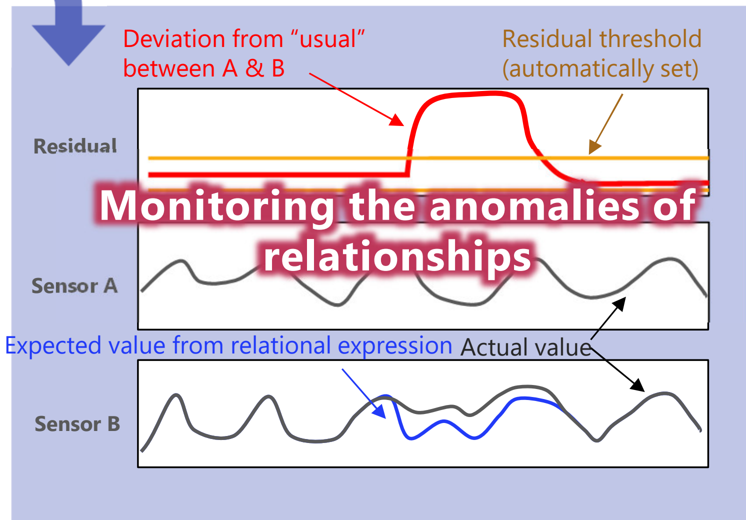
Modeling
Automatic relationship calculation and relational expression creation



Time	A	B
10:00	1.0	2.0
10:01	2.0	4.0
10:02	3.0	6.0
10:03	2.0	4.0

B(t)=2×A(t)
Relational expressions(automatically created)

Anomaly detection
Detect signs of anomalies at an early stage by comprehensively looking at all relationships



Overview of System Invariant Analysis Technology(SIAT)

This technology focuses on the relationships between sensors and detects abnormal behaviors very early and with high accuracy

- Easy-to-understand in manufacturing & maintenance sites
- Not require data scientists
- User interface for use for on-site
- Rich client tool and Python interface for analysts

SIAT in Manufacturing and Plants

Various use cases such as Anomaly detection, Predictive maintenance, and Quality deterioration are increasing in areas with high economic and social impact

safety

efficiency

Section

03

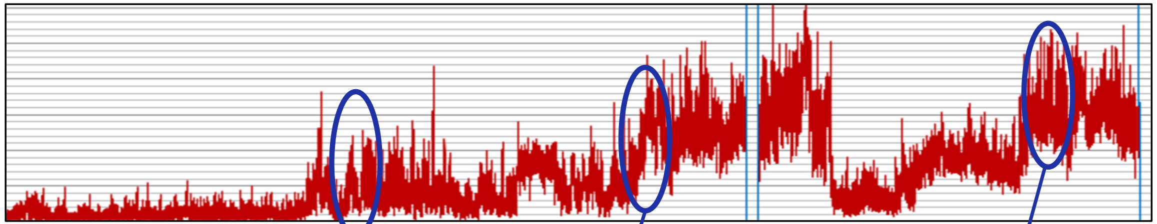
Case study

1. Thermal power generation boiler monitoring
2. Inspection of Spacecraft “Orion”

1. Thermal power generation boiler monitoring

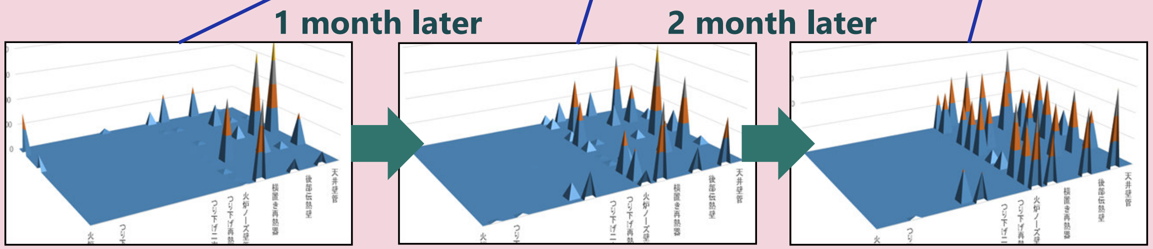
Visualization of state changes (modulation of metal temperature due to clinker generation, etc.) in the boiler furnace over time and from the viewpoint of the part

SIAT
Anomaly score graph
(Transition of invariant destruction)



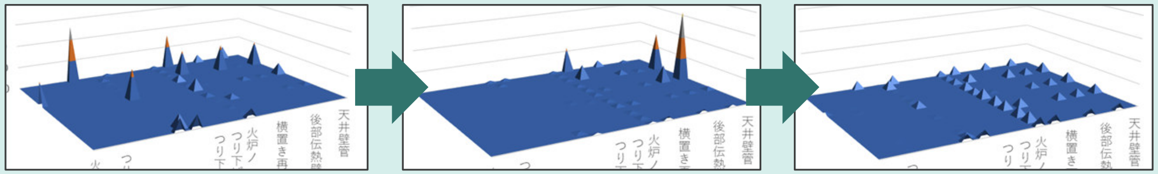
Anomaly case

Accumulation of clinker in the furnace gets worse



Normal case

Normally, the site returns to original state when the clinker peels off



Results

- ✓ Cleanup due to clinker ash accumulation, panel blockage, etc. in areas where the degree of anomaly score is high
- ✓ The state of the site that cannot be confirmed from the outside can be visualized by the collapse of the invariant

Section

03

Case study

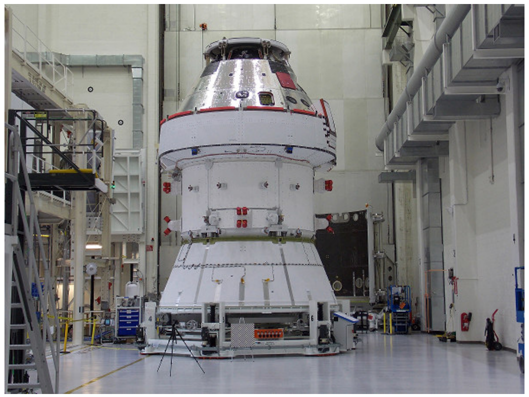
1. **Thermal power generation boiler monitoring**
2. **Inspection of Spacecraft “Orion”**

Thermal vacuum test of spacecraft "Orion"

1. Detects small abnormalities that are different from the model in the normal state, detects the possibility of failure such as abnormalities and events at an early stage.
2. Identify the root cause of the failure by modeling the entire system
3. By modeling the status monitoring data history, the entire system can be grasped even in a complicated system. Contributing to strengthening support for various missions and speeding up aircraft manufacturing

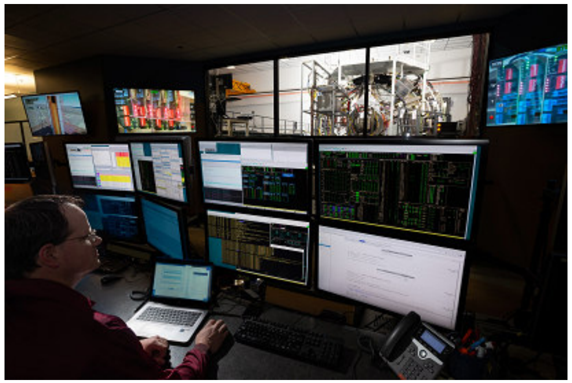
Collection and accumulation of time series data

Accumulate time-series data collected from approximately 150,000 sensors in all subsystem in a thermal vacuum test



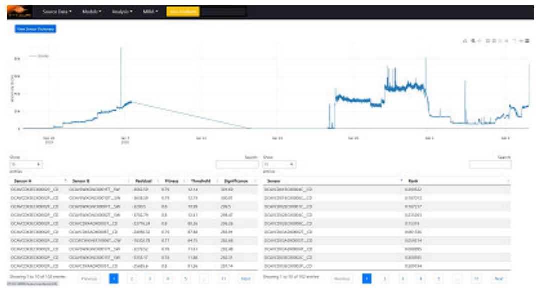
Modeling the normal state

Automatically build over 22 billion relationships between sensors to model the normal behavior of a spacecraft



Early detection of possible failure

Using the model under normal conditions, compare with the results of the subsequent thermal vacuum test. Make sure all subsystems are working properly



Section

04

Abnormality detection by sound

3.1 Common challenges of Anomaly detection using sound data

1. Processing Back Noise

- Background noise must be reduced in advance by various methods.
- Various companies use various methods, but if the frequency band of the abnormal sound overlaps with the frequency band of the noise, the abnormal sound may be muffled.

2. Sensing (sound collection)

- Specialized microphones are likely to be used in many cases, tend to be expensive.
- Installation and wiring of recording equipment is difficult
- When centralized monitoring is used, there is a high possibility of issues with the data collection network.

3. Abnormality detection by AI

- Most likely to use neural network technology such as deep learning after extracting features
- Judgment is limited to OK/NG

4. Response after abnormality detection

- Current solutions can only detect abnormalities and cannot analyze the cause. If the characteristics of the sound that caused the abnormality are not known, countermeasures are likely to be time-consuming.
- Difficult to identify similar anomalies when they occur

3.2 Capability of SIAT Anomaly detection using sound data

1. Processing Back Noise

- Learning is possible **with noise included**
- **Noise is also defined as the "usual state**"

2. Sensing (sound collection)

- General microphone installation only
- **Easy to get started** with **inexpensive** equipment
- **No need to modify existing equipment**

3. Abnormality detection by AI

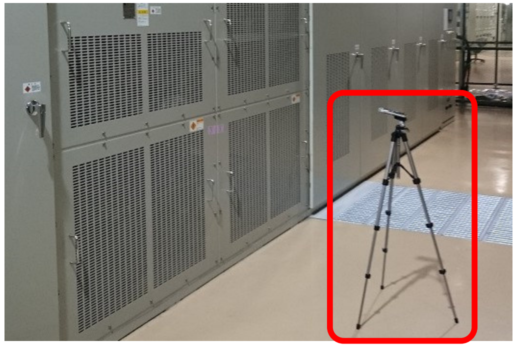
- It is possible to detect **which frequency characteristics are abnormal**

4. Response after abnormality detection

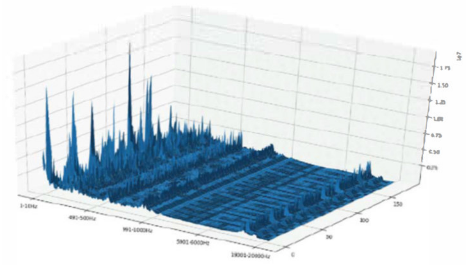
- **Similar events can be determined** from the frequency characteristics of anomalies and trends

3.3 Model Creation Steps

1. Decompose PCM recorded wav data into frequencies using FFT
2. Automatically extract invariant relationships between frequencies using SIAT



1. WAV data



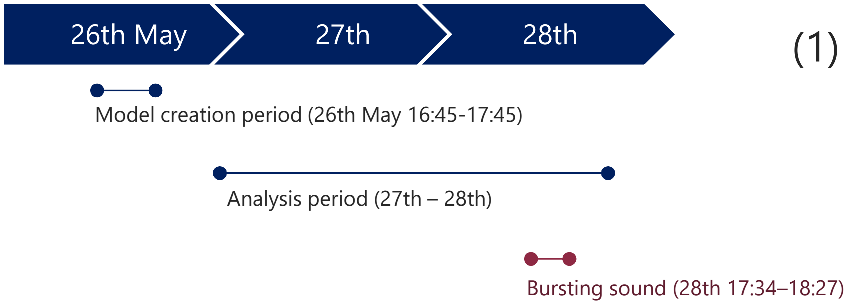
Frequency decomposition by FFT

2. CSV data

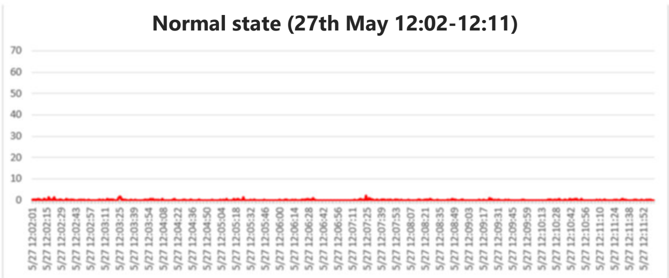
Model the relationship between frequencies

Assumes that focusing on the invariant relationship between frequencies creates an anomaly detection model that is robust to ambient noise

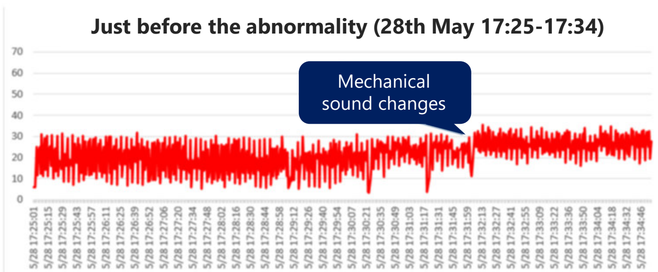
3.4 Anomaly detection



(1) Model in one hour (16:45-17:45) on May 26

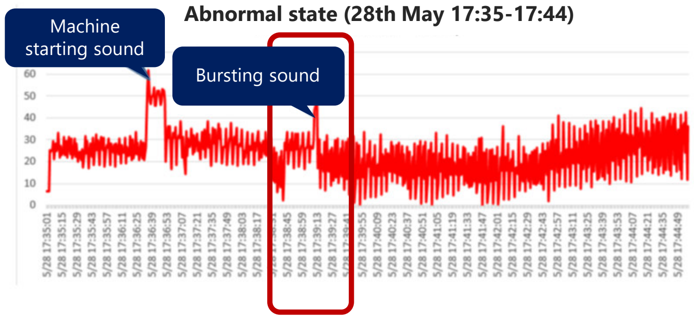


(2) Check the state of the model in the normal period.
- Anomaly score is stable near 0
- It is thought that the model learns including various surrounding noises.

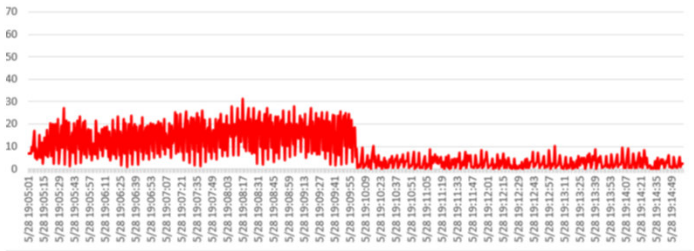


(3) Verify whether anomaly detection is possible using anomaly periods
- Abnormality score is clearly different from the normal period
- It is thought that the abnormal noise is detected at a level that cannot be detected by humans.

3.5 Anomaly detection



(4) Abnormalities
- Abnormality occurs in the red frame area.
- Subsequent anomaly score remains high and transitions



(5) Failed inverter is shut down
- Abnormality score becomes low and remains stable

The system was able to accurately capture abnormal noises even in areas with high ambient noise.

3.6 Usage scenarios & Needs for Anomaly detection by sound

Inspection (Good/Fail)

Mechanization of sensory inspections that rely on veterans

- Standardization of inspections
- Shortening of inspector training period
- Explanation of results based on evidence
- Prevention of missed inspection

Abnormality detection during manufacturing

- Optimization of tool replacement time
- Abnormality detection of materials

Monitoring (detection of predictive failure)

Real-time monitoring

- Constant noise monitoring
- Detection of signs of failure of rotating machines
- Detection of abnormalities in power supply equipment
- Reduction of the burden of inspection patrols

Watching over/preventing crime

Privacy-conscious monitoring

- Detection of anomalies beyond visual range
- Realization of monitoring that cannot be done with images
- Identification of sounds of objects breaking/screams

Medical field

Medical assistance in the medical field

- Reduce the workload of laboratory technicians
- Identification of conditions by voice and sound

Section

05

Sensing Devices

1. **Acoustic Analysis Gateway**
2. **Optical Fiber sensing**

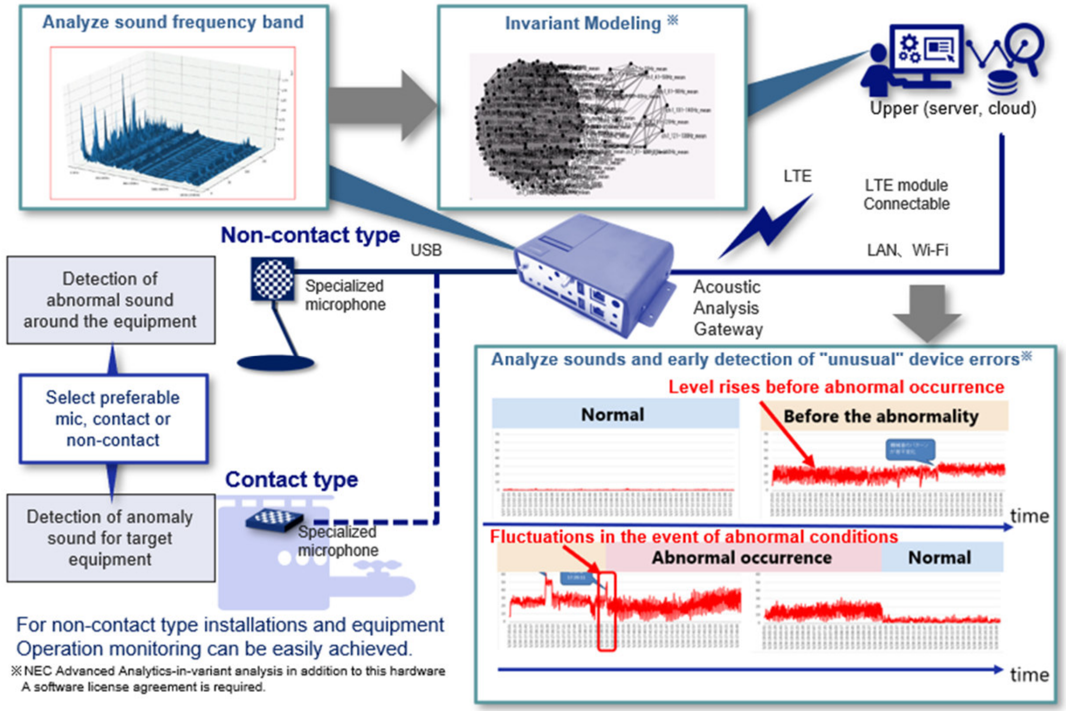
Acoustic Analysis Gateway for Equipment Operation monitoring

Acoustic Analysis Gateway is hardware that records, analyzes, and transfers sound from various devices over a wide band.

- Acoustic data is gathers by a dedicated waterproof microphone, and frequency is decomposed by FFT and transferred to a host computer (server, cloud, etc.). Compact and easy to install.

- Specialized microphones that detect sounds in a wider than the audible range allow you to record sounds around your equipment or attach them directly to the equipment for direct recording of the vibrations of them.

- By decomposing broadband sounds into each frequency band for analysis, the operating status of customers' equipment can be grasped in detail.



Section

05

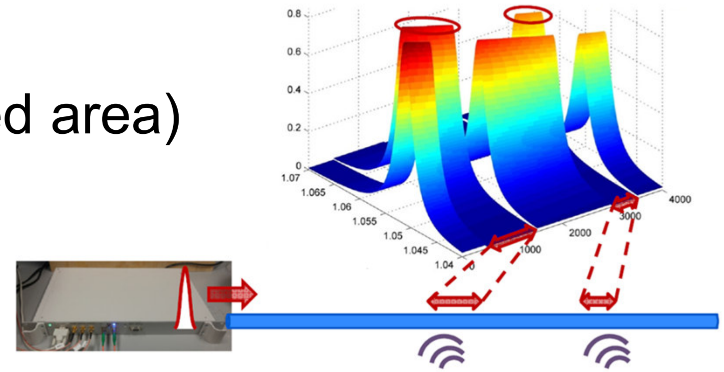
Sensing Devices

1. **Acoustic Analysis Gateway**
2. **Optical Fiber sensing**

Features Fiber Sensing

Vibration-centric sensing technology using optical fiber

- High-density (several meters granularity) vibration/temperature sensing over a wide area (tens of kilometers)
- High environmental tolerance without being affected by electromagnetic noise
- Does not require communication equipment or lines to transmit observation data
- Does not require power supply to the sensing point
  Low power consumption and easy maintenance
- Can be used in explosion-proof/high radiated areas
  (assuming that the device is kept out of the controlled area)
- Heat-resistant by utilizing optical fiber
  (may be usable at 700°C)
- Requires know-how on how to install the fiber



NEC vs Conventional Methodology

	NEC (DAS)	Conventional (FBG)
Measuring Method	● Capable **of multipoint measurement with ordinary unprocessed optical fiber** (SM) ● The number of points varies depending on the sensing frequency, but 5,000 points can be measured at a 1kHz sampling rate ● The frequency and number of points **can be changed by software**	● Processed fiber allows multi-point measurement up to maximum of 5 to 6 points
Measuring Accuracy	± a few nm (theoretically ± a few pm)	± a few nm (limited to distortions)
Transmission Range	~80km	~30km
Flexibility of Sensing Points	**Flexibility in changing measurement points due to software-assisted repositioning**	No flexibility due to the need to pre-fabricate the measurement points into fiber
Cost	● Equivalent or cheaper equipment compared to FBG ● Cheaper overall due to the use of general-purpose fiber	Expensive Due to difficulty to process fiber, the cost increases

Applications (Examples in Industrial Usages)

- Intrusion detection for critical facilities
- Condition monitoring by sound/abnormal sound detection
  - Human voice and abnormal sound detection and condition identification (AI application)
- Continuous monitoring of infrastructure facilities (bridges, buildings, and other structures)
- Crack detection in high-pressure/high-temperature piping
  - High-pressure steam piping in power plants
  - Continuous inspection of piping (especially in explosion-proof areas) in chemical plants
- Vibration measurement in explosion-proof areas
  - Use as low-cost vibration sensor
- Detection of cracks and bulges in CFRP tanks
  - Unattended monitoring of hydrogen stations


High judgment accuracy
Easy to understand basis of judgment
Easy to use on manufacturing site

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