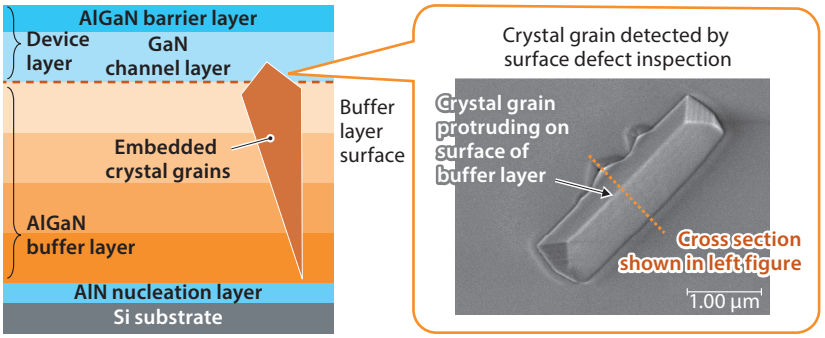
1. Research and Development

1.1 Large-Diameter GaN-on-Si Substrate Fabrication Technology for High-Reliability Power Devices



Cross-sectional structure of GaN-on-Si substrate

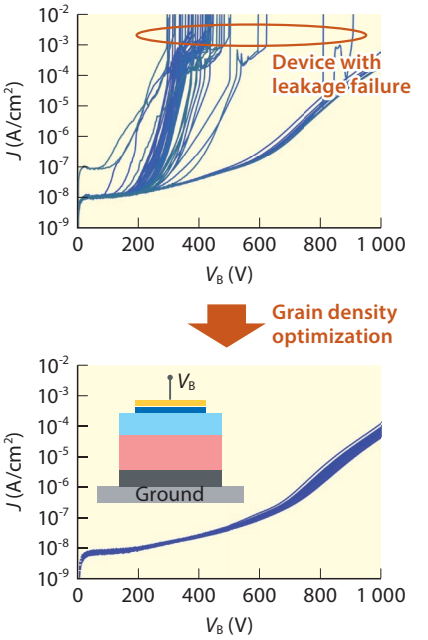
Bird's-eye-view SEM image

AlGaN: aluminum gallium nitride
AlN: aluminum nitride

Cross-sectional structure of rapidly grown GaN-on-Si wafer substrate and bird's-eye-view scanning electron microscope (SEM) image of crystal grains embedded in aluminum gallium nitride (AlGaN) buffer layer

Buffer growth condition	Grain density (10^3 per wafer)	Yield (%)
Rapid growth	47	9
Rapid growth + grain density optimization	**2**	**100**

Comparison of yields before and after buffer layer grain density optimization



V_B: applied voltage J: leakage current density

Improvement of vertical electrical properties of power devices fabricated on rapidly grown GaN-on-Si substrate with reduced grain density

Gallium nitride (GaN) power devices, which combine high breakdown voltage with high-speed switching capability, are in increasing demand as key components of energy-efficient power converters for applications such as electric vehicles and data centers.

To accelerate the widespread adoption of GaN devices, a stable supply of high-quality, cost-effective GaN substrates is essential. Accordingly, Toshiba Corporation has been developing GaN-on-silicon (Si) substrates, in which GaN epitaxial layers are grown on large-diameter Si wafers that serve as supporting substrates.

To maximize the cost advantages of GaN-on-Si substrates, it is crucial to shorten the time required to form a thick buffer layer that accommodates the lattice mismatch between GaN and Si, thereby improving throughput. However, devices fabricated on rapidly grown GaN-on-Si substrates have shown reduced yields due to an increased incidence of vertical (out-of-plane) leakage failures.

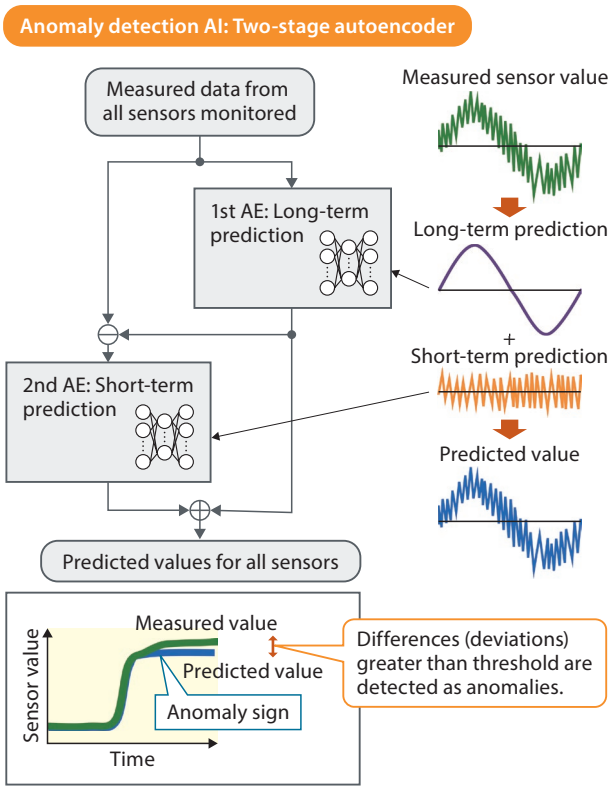
To address this issue, Toshiba Corporation conducted a physical analysis of devices exhibiting leakage defects, revealing that crystal grains embedded in the buffer layer are the primary cause of leakage current. Further investigation showed that these crystal grains form convex protrusions on the surface of the buffer layer beneath the device layer. Based on this finding, we established an evaluation method in which the density of such crystal grains—quantified

through defect inspection of the buffer layer surface—is used as a key quality index. Using this index to optimize the buffer layer growth conditions, we achieved significant improvements in both the vertical breakdown voltage and the yield of power devices fabricated on rapidly grown GaN-on-Si substrates.

The high-quality, high-throughput GaN-on-Si growth technology established in this work is expected to meet the growing demand for GaN power devices and contribute to the realization of a carbon-neutral society.

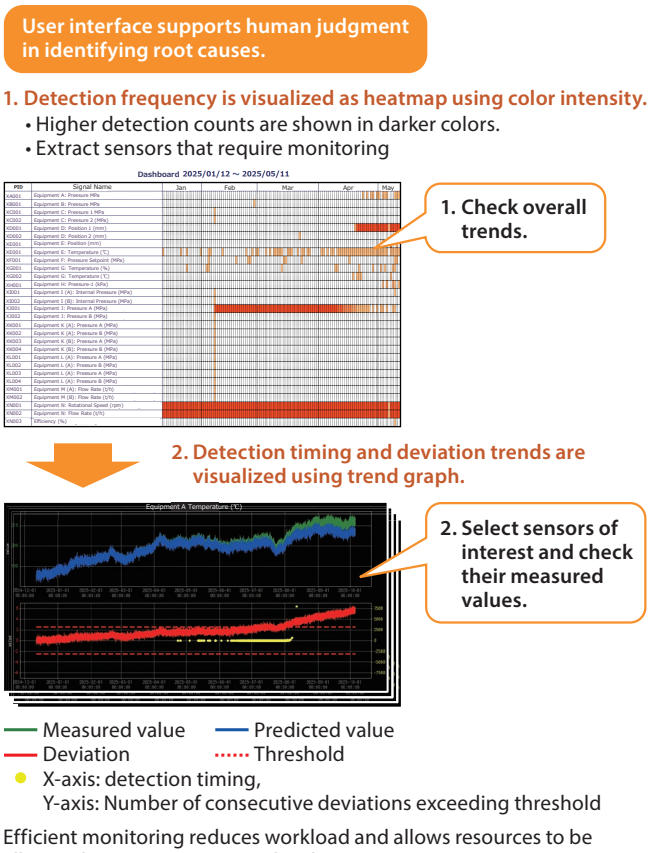
Part of these results was obtained through a project (JPNP21029) subsidized by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

1.2 Effectiveness Evaluation of Anomaly Detection AI Capable of Early and High-Accuracy Detection of Latent Anomalies in Large-Scale Industrial Plants Under Changing Conditions



AEs optimized for long- and short-term predictions are trained, and their outputs are combined to achieve high prediction accuracy.
AE: autoencoder

Two-stage autoencoder operation



Efficient monitoring reduces workload and allows resources to be allocated to countermeasure development.

User interface

Large-scale complex plants require monitoring of time-series data from thousands of sensors to detect anomalies at an early stage. To address this need, Toshiba Corporation has developed an anomaly detection artificial intelligence (AI) algorithm based on a two-stage autoencoder. By training this AI algorithm to learn complex relationships across large volumes of time-series data, it becomes possible to detect early signs of anomalies embedded within plant state changes with high accuracy—signs that were previously difficult to capture using conventional methods.

The new AI algorithm enables condition-based maintenance (CBM) tailored to the state of the detected anomalies or degradation, thereby facilitating efficient plant operation and maintenance while improving plant availability.

From 2020 to 2022, a demonstration test was conducted at the Mikawa Power Plant operated by Sigma Power Ariake Co., Ltd., a subsidiary of Toshiba Corporation. Through online monitoring of large-scale operational data, the effectiveness of early detection of latent anomaly precursors was confirmed. In February 2024, we launched both cloud-based and on-premises

services incorporating this AI algorithm as part of TOSHIBA SPINEX for Energy, a software-as-a-service (SaaS) digital service for power utilities and manufacturing industries.

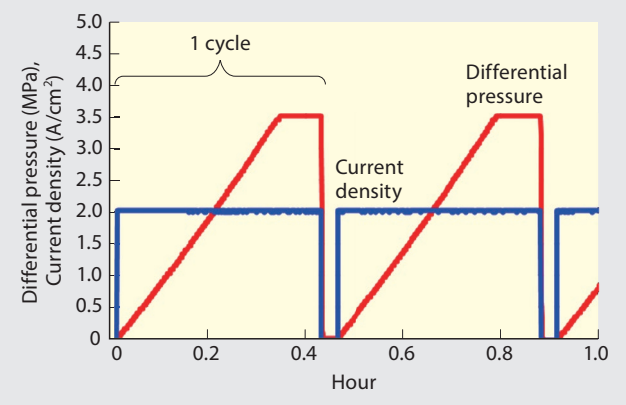
Since November 2024, a trial evaluation has been conducted using operational data from Onagawa Nuclear Power Station Unit 2 in cooperation with Tohoku Electric Power Co., Inc., to verify the effectiveness of an anomaly prediction system based on the two-stage autoencoder. This evaluation includes the following:

(1) The anomaly prediction system monitors more than a thousand operational parameters—such as temperature, pressure, and flow rate—across various plant systems and equipment, enabling early detection of anomaly signs that are difficult to identify through human observation alone.

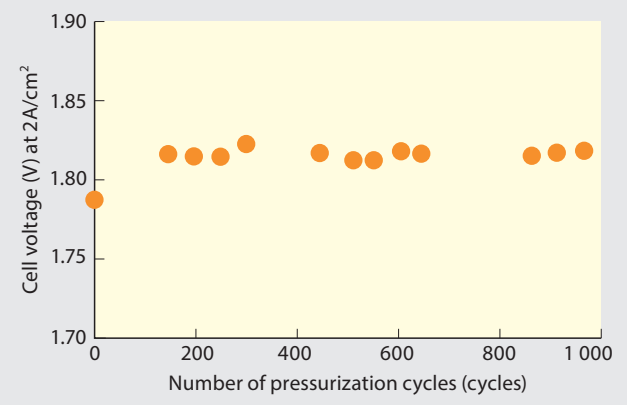
(2) For operational parameters in which anomaly signs are detected, human operators continuously monitor and evaluate measurement trends and consider appropriate countermeasures before alarms are triggered.

This anomaly detection system enables early identification of anomaly precursors in operational parameters that might otherwise be overlooked by human-based monitoring alone, thereby demonstrating its practical effectiveness.

1.3 Durability Validation of 90%-Iridium-Reduced MEA Using High-Pressure Gas Safety Act–Compliant PEM Water Electrolysis Evaluation Platform



Pressure cycling profile for testing MEA durability



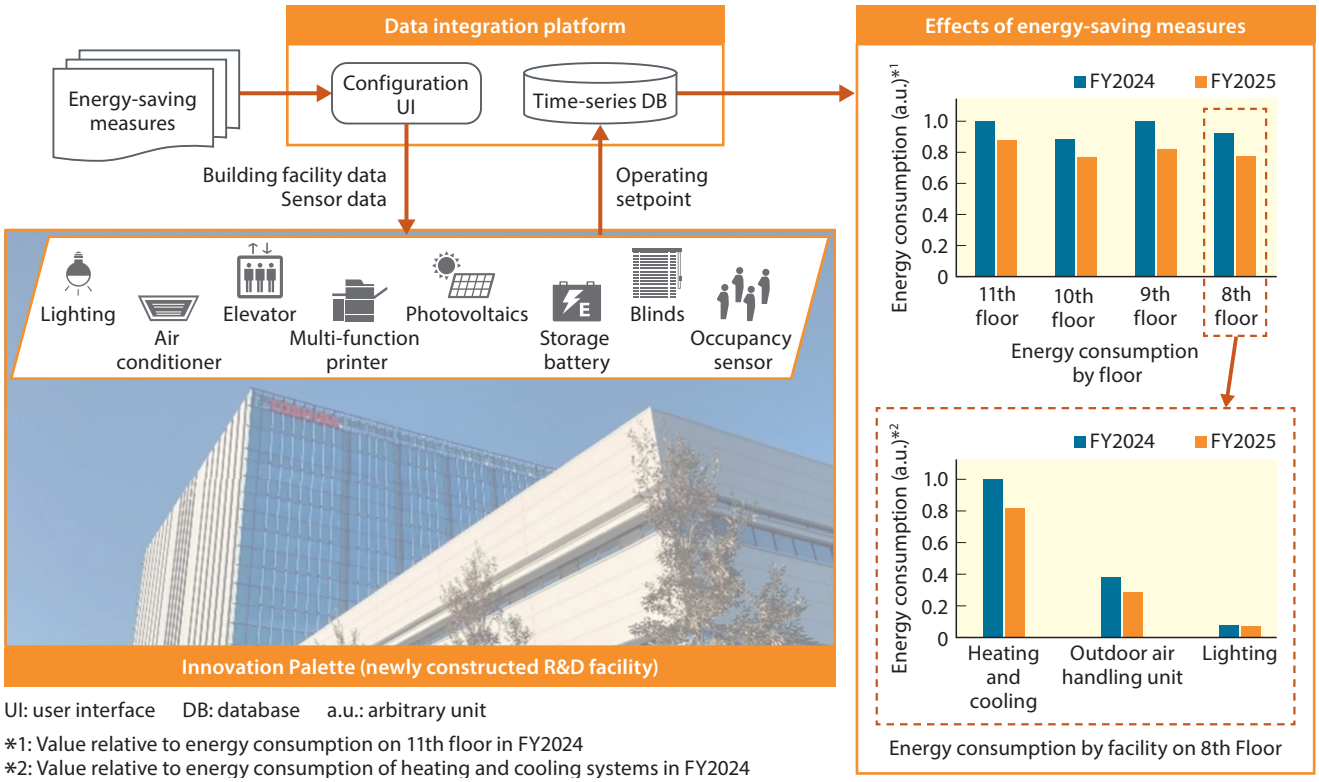
Correlation between pressurization cycles and MEA cell voltage

Power-to-gas (P2G) is a technology that produces green hydrogen via water electrolysis for subsequent storage and transportation. In this field, Toshiba Corporation has established an evaluation environment compliant with Japan's High-Pressure Gas Safety Act, enabling differential-pressure operation of up to 5 MPa. Using this environment, we conducted pressurization cycle tests on a membrane electrode assembly (MEA) incorporating an electrode catalyst with iridium loading reduced by 90% (0.15 mg /cm^2) compared with conventional MEAs, and confirmed its high durability.

While proton exchange membrane (PEM) water electrolysis offers excellent load-following capability and durability for green hydrogen production in P2G systems, it requires substantial amounts of the scarce element iridium. To address this issue, we have proposed a low-iridium MEA based on iridium oxide nanosheet lamination technology, achieving performance comparable to that of conventional MEAs with only one-tenth the iridium loading. For overseas deployment, however, it is necessary to ensure performance and durability under pressurized operation in the range of 2 to 5 MPa to meet requirements for hydrogen storage and transportation.

In Japan, testing at pressures above 1 MPa has been challenging due to the requirement for compliance with the High-Pressure Gas Safety Act. However, through coordination with relevant organizations, a PEM water electrolysis evaluation system capable of operation at pressures up to 5 MPa was successfully installed. Using this system, we conducted pressurization cycle tests involving repeated cycles between high pressure (3.5 MPa) and atmospheric pressure to simulate startup and shutdown conditions. The results indicated virtually no degradation of the MEA, demonstrating its excellent durability. Going forward, we will evaluate the MEA in combination with next-generation thin electrolyte membranes currently under development to achieve higher efficiency, thereby contributing to the wider deployment of P2G.

1.4 Energy-Saving Solution Support System Demonstrating Reduced Power Consumption Through Data Integration Across Multiple Facilities



UI: user interface DB: database a.u.: arbitrary unit

*1: Value relative to energy consumption on 11th floor in FY2024
*2: Value relative to energy consumption of heating and cooling systems in FY2024

Energy-saving solution support system

To achieve carbon neutrality in buildings and offices, it is essential to reduce energy consumption by improving the operational efficiency of building facilities such as heating, ventilation, and air conditioning (HVAC) and lighting systems, while maintaining occupant comfort. Traditionally, these systems within buildings have been managed and operated independently, making it difficult to optimize energy efficiency through integrated operation.

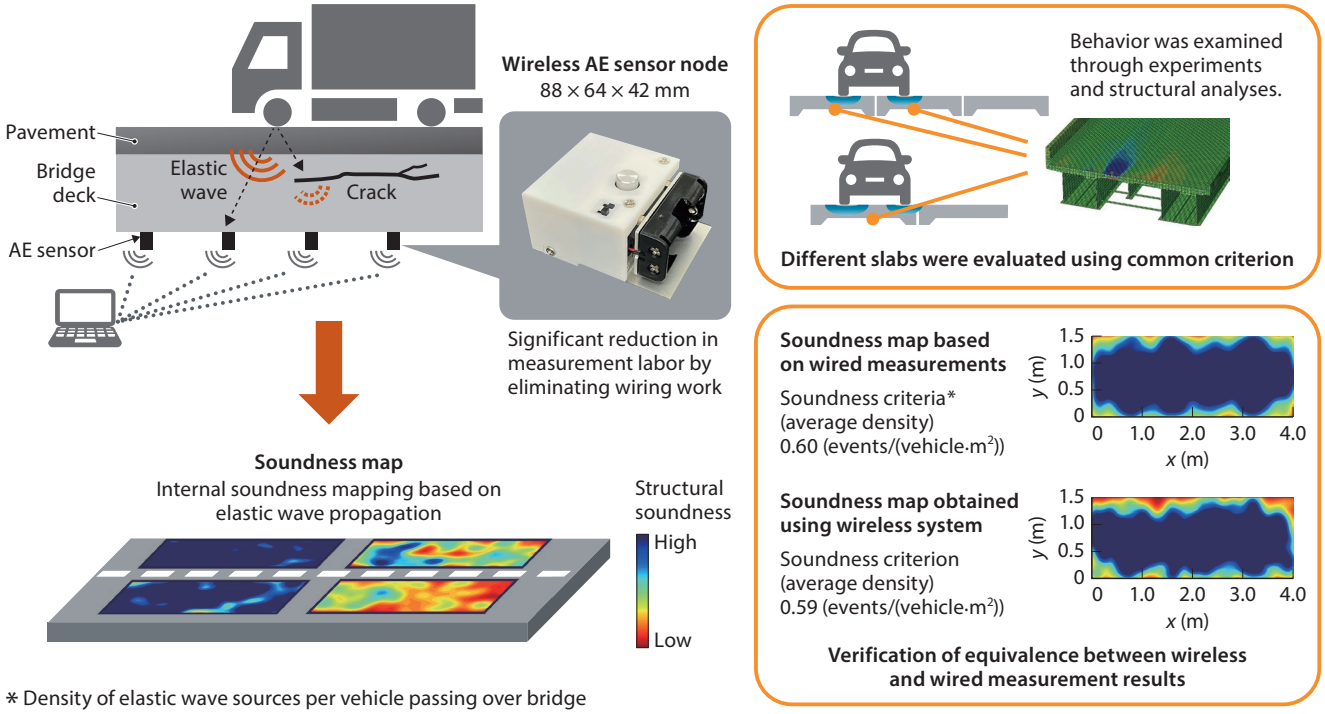
To address this issue faced by energy consumers and to facilitate the development of related business services, Toshiba Corporation has developed a data integration platform technology that enables integrated management of multiple facilities via web application programming interfaces (APIs). This technology allows real-time sharing of live data among multiple systems, including HVAC control systems, lighting control systems, and occupancy-sensing systems, thereby enabling seamless inter-system coordination. As a result, operational patterns required for implementing energy-saving measures across multiple facilities can be applied in an integrated manner.

An energy-saving solution support system incorporating this data integration platform technology was deployed in Innovation Palette, a newly constructed research and development (R&D) facility of the Toshiba Group, and its effectiveness was validated through practical

implementation of energy-saving operations. A demonstration test was conducted over a two-month period from July to August 2025. Energy-saving measures included switching air-conditioning and lighting systems on and off based on office occupancy detected by occupancy sensors, as well as dimming lighting in designated areas according to time periods. As a result, it was confirmed that power consumption on the 8th to 11th floors of Innovation Palette was reduced by approximately 12% compared with the same period in fiscal year 2024.

Going forward, we will continue demonstration activities at Innovation Palette to verify the effectiveness of the energy-saving solution support system for commercialization, while optimizing operational strategies and expanding system functionality, thereby contributing to the realization of carbon-neutral buildings and offices.

1.5 Bridge Deck Soundness Evaluation Service Using Internal Deck Soundness Mapping Technique



* Density of elastic wave sources per vehicle passing over bridge

Overview of internal deck soundness mapping

In recent years, the maintenance and management of aging social infrastructure have become critical societal challenges. To address these challenges, Toshiba Corporation has developed an internal deck condition mapping technique using acoustic emission (AE) sensing technology. This technique has been listed in the Performance Catalog of Inspection Support Technologies issued by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan. Furthermore, Toshiba Plant Systems & Services Corporation has launched an inspection service utilizing this technique and has secured a contract for the integrity assessment of bridge slabs on expressways.

The internal deck condition mapping technique non-destructively identifies the distribution of damage within bridge slabs by installing AE sensors on the underside of the slab and analyzing the propagation characteristics of elastic waves generated as vehicles pass over the bridge. Furthermore, visualizing internal damage conditions as a soundness map enables more effective prioritization of repair targets and verification of repair effectiveness.

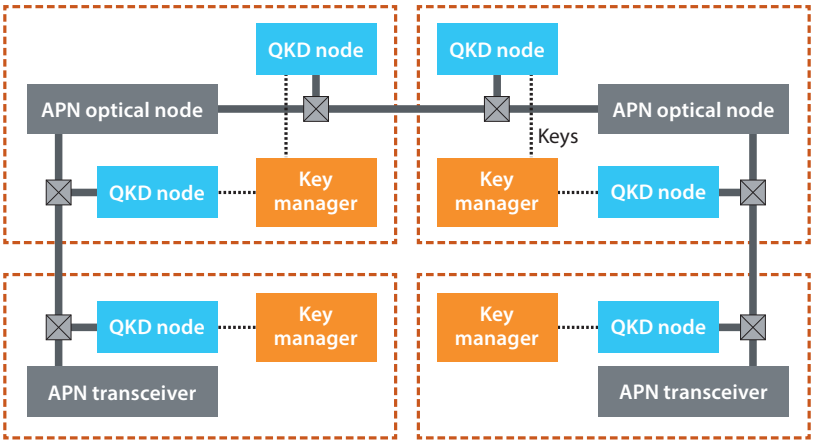
Applications such as repair prioritization require quantitative comparison of evaluation results obtained from different bridge slabs based on common criteria. Because the evaluation results are affected by factors such as temperature and pavement type, compensation processing is applied. In addition, because the generation of elastic waves is influenced by pavement deformation caused by vehicle loads, differences in slab configuration or vehicle travel paths may lead to variations in evaluation results. To address this issue, experimental studies and

structural analyses were conducted to clarify these effects, thereby identifying the conditions necessary for quantitative comparison and establishing a standardized evaluation methodology.

Moreover, to reduce the workload associated with on-site operations such as sensor wiring, a proprietary wireless AE sensor system was introduced. Through experimental optimization, the wireless system achieved evaluation results equivalent to those obtained with conventional wired measurements, demonstrating its practicality for field deployment. This wireless system significantly improved operational efficiency and enabled inspection services for large bridge areas.

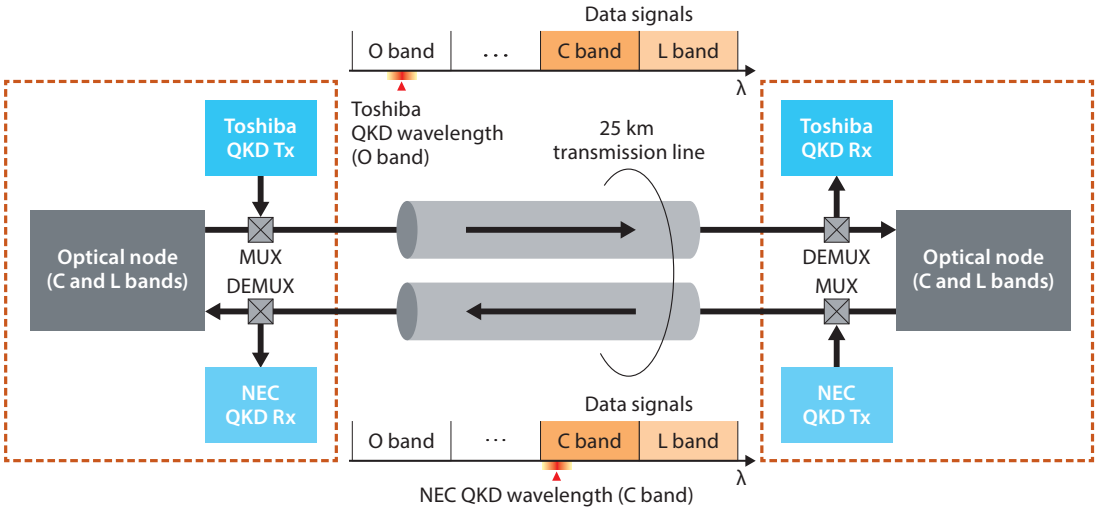
Going forward, we will continue to expand this service and contribute to the advancement of infrastructure maintenance technologies.

1.6 Demonstration of Quantum Key Distribution System Integration into All-Photonic Networks for Telecommunication Carriers



⊠: MUX/DEMUX

Example of IOWN APN and QKD network integration



MUX: multiplexer DEMUX: demultiplexer Tx: transmitter Rx: receiver

Experimental setup to demonstrate coexistence of QKD and high-capacity optical transmission systems

Quantum key distribution (QKD) enables the information-theoretically secure distribution of cryptographic keys required for encrypted communications. Toshiba Corporation has successfully conducted the world's first demonstration of multiplexed transmission of QKD signals and key generation(*1) within a system environment designed for the IOWN (Innovative Optical and Wireless Network)(*2) Open APN (All-Photonic Network)(*3). For this demonstration, a large-capacity optical transmission system was constructed at the Quantum ICT Collaboration Center of the National Institute of Information and Communications Technology (NICT), Japan, using optical transmission equipment constituting the Open APN. Experiments were conducted to multiplex high-speed data signals with two different types of QKD signals,

developed by Toshiba Corporation and NEC Corporation, respectively, over the same transmission link.

The quantum channel signals, together with their associated control signals, were transmitted over a set of optical fibers. Dummy optical signals for data communication, corresponding to a total capacity of 47.2 Tbps (T: tera=10^{12}), were multiplexed with the QKD signals on the same fiber across the full C- and L-band wavelength ranges, which are expected to be deployed in the optical backbone networks of telecommunication carriers. Wavelength allocation was carefully designed to prevent inter-signal interference, and the signals were co-propagated over a 25 km optical fiber link. Under these conditions, we confirmed that simultaneous cryptographic key generation using two different QKD protocols and error-free transmission of high-speed, high-capacity data can be achieved.

The demonstration indicates the potential to integrate QKD networks with telecommunication carriers' optical networks, such as IOWN Open APN, without the need for dedicated optical fibers for QKD signals, thereby paving the way for the provision of wide-area, cost-effective quantum cryptographic communication services in the future.

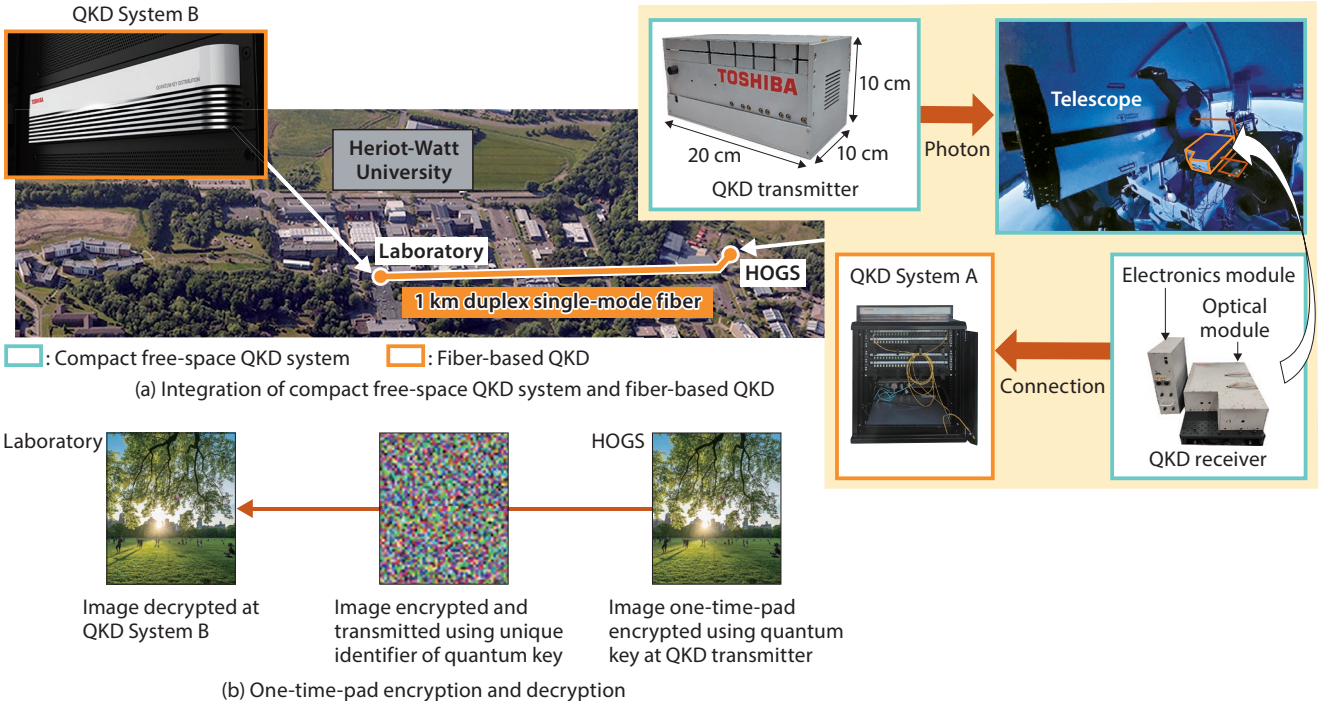
This project was partially funded by the Ministry of Internal Affairs and Communications of Japan through the ICT Priority Technology Project, Research and Development for Construction of a Global Quantum Cryptography Network (JPMI00316).

(∗1) As of July 1, 2025 (according to Toshiba Corporation, NEC Corporation, and NICT research)

(∗2) A concept for a network and information processing infrastructure that leverages advanced optical technologies to provide high-speed, large-capacity communication and vast computational resources

(∗3) Low-power, high-quality, high-capacity, low-latency photonic networks whose functional architecture is being defined by the IOWN Global Forum

1.7 Toward Seamless Integration of Satellite and Fiber-Based Quantum Key Distribution Systems



Demonstration system configuration for integrated satellite- and fiber-based QKD

Satellite-based quantum key distribution (satellite QKD) is a promising approach for establishing a global quantum-secured network spanning multiple continents. The feasibility of satellite-to-ground QKD links has already been demonstrated. However, for deployment on satellites and installation at ground stations, achieving compact size, low weight, and low power consumption is essential to address launch-cost and site constraints. In addition, seamless integration with terrestrial fiber-based QKD is indispensable for practical applications.

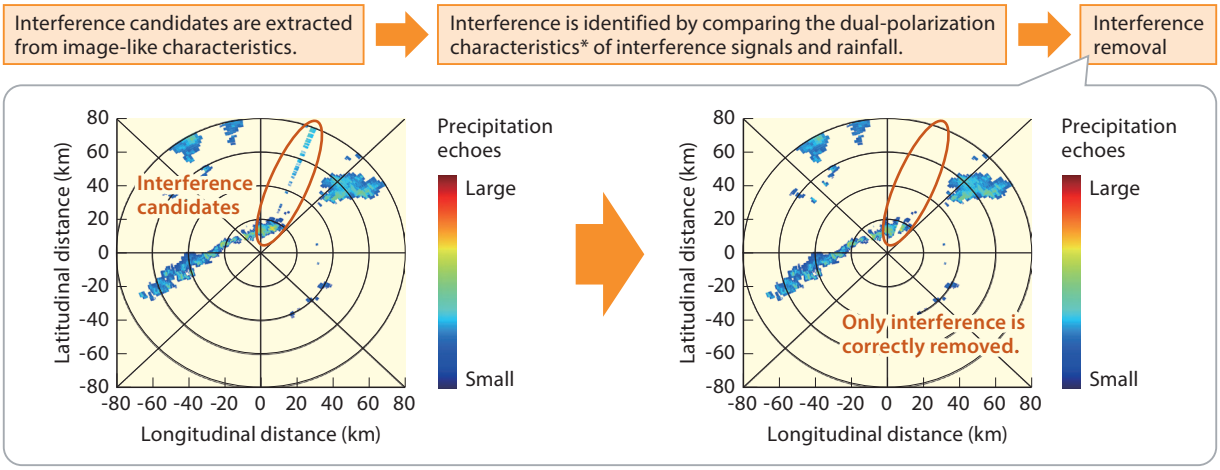
Toshiba Europe Ltd. has developed a compact free-space QKD system for satellite-to-ground links. The QKD transmitter measures 10 cm (depth) × 20 cm (width) × 10 cm (height), weighs 2 kg, and operates at 16 W. To the best of our knowledge, this is the smallest, lightest, and lowest-power quantum transmitter operating at GHz clock rates(*). The QKD receiver consists of an optical module measuring 30 cm × 40 cm × 10 cm, including single-photon detectors, and an electronics module. Both the QKD transmitter and receiver employ a system-on-module (SoM) architecture that enables execution of the QKD protocol, key-processing algorithms, and key management functions compliant with the European Telecommunications Standards Institute (ETSI) Group Specification (GS) QKD 014 standard. The compact free-space QKD system was installed at the Hub Optical Ground Station (HOGS) of Heriot-Watt University in Scotland. By injecting photons from the QKD transmitter into the telescope to emulate satellite transmission and receiving them with the QKD receiver, real-time quantum key generation was successfully demonstrated.

To verify interoperability between satellite QKD and terrestrial QKD systems, the free-space QKD system was integrated with a fiber-based QKD system. Two Toshiba QKD systems, designated Systems A and B, were installed at HOGS and at a laboratory located 1 km away, respectively, and were connected via optical fiber. Real-time generation and relay of quantum keys over free-space and fiber channels were successfully achieved, enabling one-time-pad encryption and decryption of image data. The integrated system operated stably for four consecutive days, demonstrating the feasibility of an integrated global quantum communication network.

This research was funded through Innovate UK (Project No. 10089202).

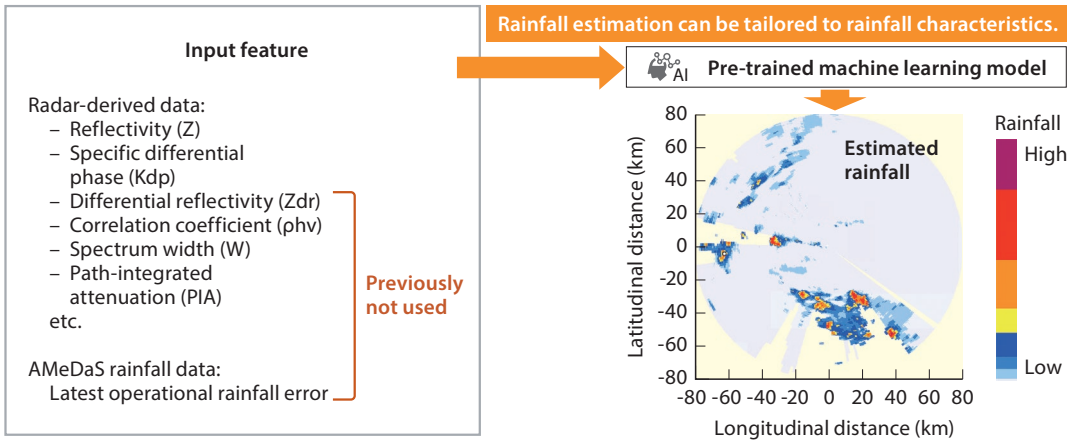
(*) As of December 2025 (according to Toshiba Europe Ltd. research)

1.8 Weather Radar Data Analysis Techniques for Real-Time Rainfall Monitoring Services



* Characteristics such as differential reflectivity and correlation coefficient obtained by using both horizontal and vertical polarizations

Weather radar interference removal using combined image features and dual-polarization information



Rainfall estimation using machine learning models

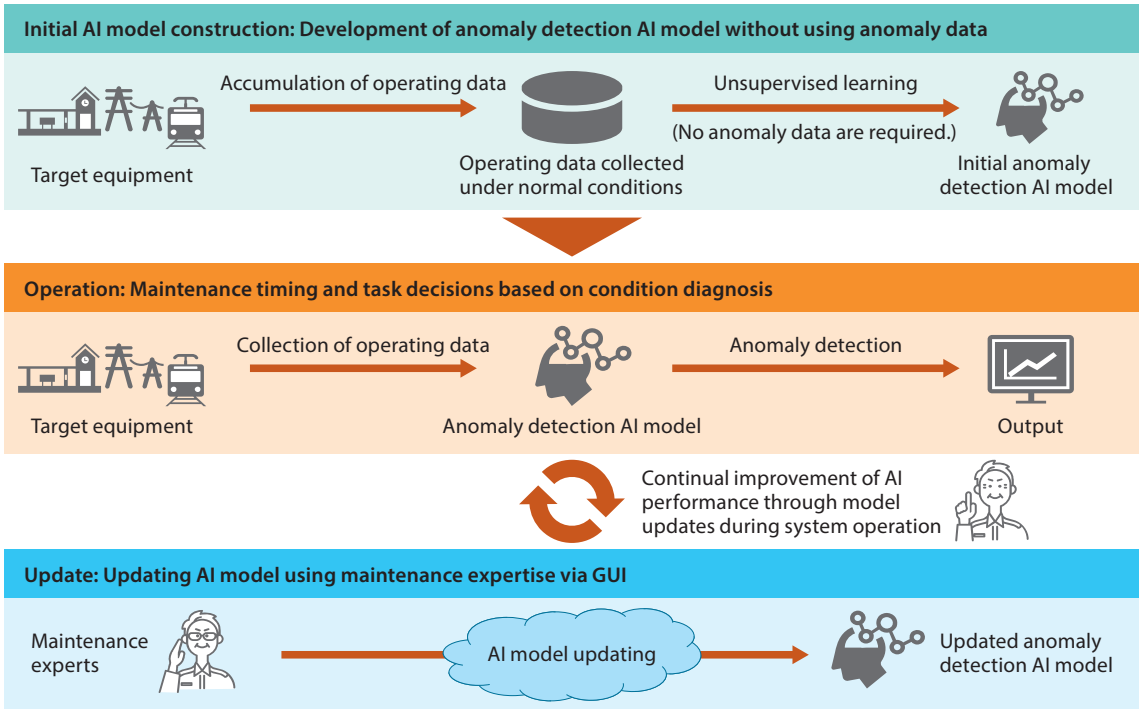
Rainfall monitoring services that provide real-time ground rainfall estimates using weather radar observation data require two processing steps: (1) a preprocessing step to remove unwanted signals (e.g., interference) from radar data and thereby improve data quality and (2) a post-processing step to estimate rainfall amounts from the preprocessed data.

For the preprocessing step, Toshiba Corporation has developed an interference removal technique that addresses inadvertent elimination of valid precipitation echoes during interference suppression. The new technique combines the image-like characteristics of interference and differences in the dual-polarization properties between interference signals and precipitation echoes in order to distinguish between them. Verification using representative interference cases confirmed that this technique successfully eliminates interference without erroneously removing precipitation echoes.

For the post-processing, we have developed a machine learning-based rainfall estimation method to improve accuracy under diverse rainfall conditions, including typhoons, localized torrential rain, and frontal precipitation. This method incorporates features not used in conventional radar-based approaches, such as additional radar-derived parameters and historical rainfall data from the Automated Meteorological Data Acquisition System (AMeDAS). As a result, for the targeted rainfall events, the root mean square error (RMSE) of the estimated rainfall relative to the observed rainfall was improved by more than 20% compared with conventional methods in nearly all cases.

We will incorporate both the preprocessing and post-processing techniques into cloud-based services in the future.

1.9 Continual Improvement of Anomaly Detection AI Leveraging Maintenance Expertise



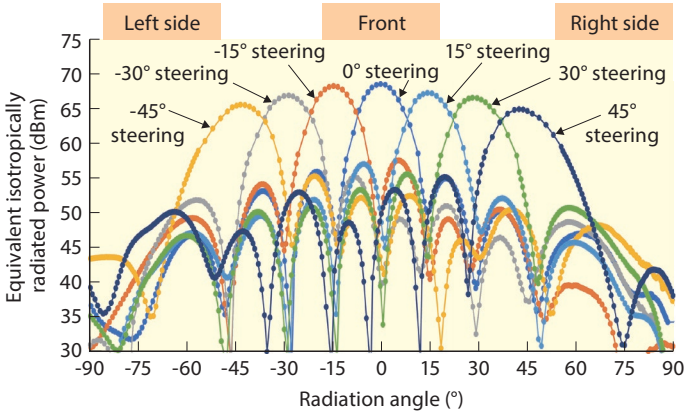
Overview of continual improvement of anomaly detection AI models

CBM techniques, which assess the condition of in-service equipment to determine the appropriate timing and scope of maintenance activities, are attracting increasing attention as a means of improving the efficiency of infrastructure maintenance. In this context, Toshiba Corporation has been investigating AI-based CBM that detects anomalies by learning patterns in equipment operating data. However, it is difficult to collect sufficient training data for rarely occurring anomalies. Consequently, AI models require tuning based on the expertise of experienced maintenance personnel, which has posed a barrier to the practical implementation of AI-based CBM.

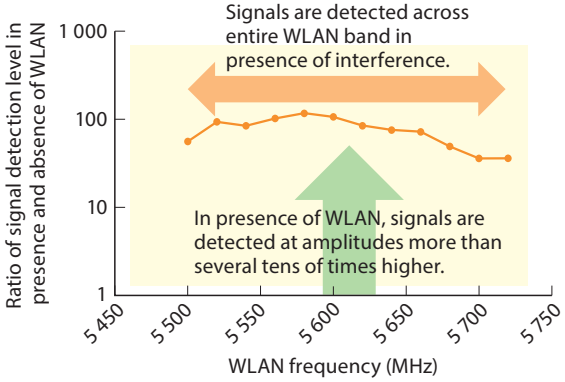
To address this challenge, we have developed a technology that constructs an initial AI model using unsupervised learning without requiring anomaly data and subsequently enables its continual improvement by leveraging the expertise of maintenance personnel during operation. Through a graphical user interface (GUI), maintenance personnel can easily provide feedback on the validity of anomaly detection results, thereby enabling iterative updating of the AI model and continual enhancement of anomaly detection performance.

We conducted a demonstration experiment on station equipment maintained by a Toshiba Group company and confirmed the effectiveness of incorporating the expertise of experienced personnel in improving anomaly detection performance. In addition, compared with conventional approaches, the new technology is expected to reduce the effort required for AI model updating by 90% or more, achieving a level suitable for practical implementation.

1.10 Technical Development for Obtaining License for Microwave Wireless Power Transfer System



Radiated power level at radiation angles using beamforming



Evaluation results of WLAN detection level characteristics in presence of interference

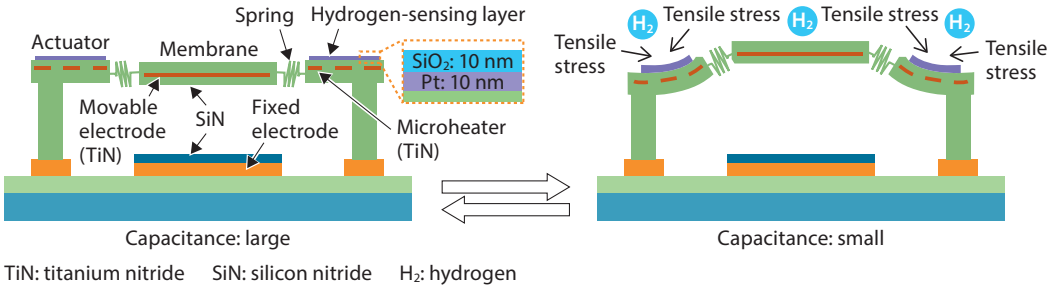
Toshiba Corporation is developing a microwave wireless power transfer (MWPT) system capable of delivering electrical power over distances of several meters. The proposed MWPT system employs a beamforming technique in which signals from multiple antennas are precisely controlled to concentrate radiated microwave power onto a specific receiver, thereby enabling efficient power transfer.

In Japan, recent revisions to the Radio Act have made it possible to operate MWPT systems as licensed radio stations. To obtain such a license, it is necessary to ensure that the system does not cause harmful interference to existing radio services, such as wireless LANs (WLANs) and radio astronomy observatories.

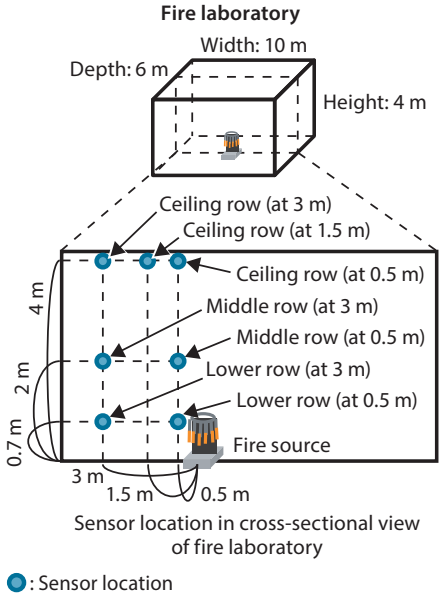
The proposed system operates in the 5 GHz band. To prevent interference with wireless LAN communications operating in the same frequency band, it is essential to detect the communication status of wireless LAN signals. Accordingly, the radio-frequency (RF) front end was designed using a low-cost analog circuit configuration capable of wideband signal detection. Furthermore, an architecture that minimizes the number of digital signal processing blocks enables a cost-effective power transfer unit. Evaluation results confirmed that the proposed system can deliver more than 500 mW of power at a distance of 3 m. In addition, a separate measurement confirmed the successful detection of WLAN signals.

These results indicate that the proposed system operates without causing interference, enabling coexistence with WLAN systems in the 5 GHz band. In addition, the proposed system achieved a reduction in high-frequency noise levels that could impact radio astronomy observations, thereby confirming compliance with the requirements of the Radio Act.

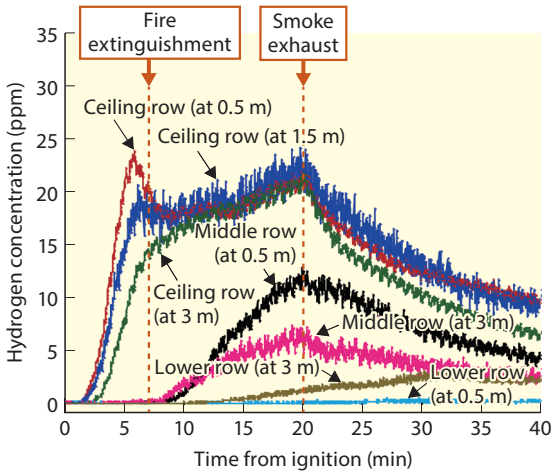
1.11 Smoldering Fire Detection Using Capacitive MEMS Hydrogen Sensor



Principle of MEMS hydrogen sensor operation



Cross-sectional view of fire laboratory with hydrogen sensors installed



Hydrogen concentration derived from sensor outputs

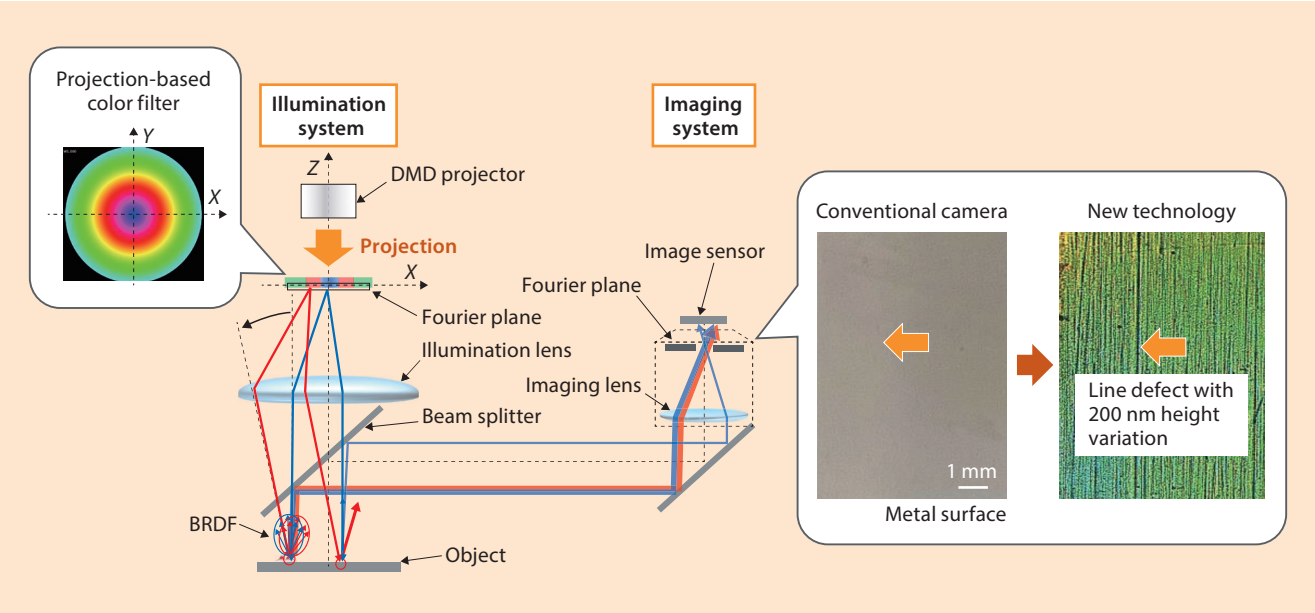
Incipient fire detection is critical to preventing evacuation delays caused by carbon monoxide poisoning and other hazards. Accordingly, Toshiba Corporation has developed a capacitive microelectromechanical systems (MEMS) hydrogen sensor capable of highly sensitive detection of trace hydrogen at ppm levels generated in the early stages of a fire.

The actuator of the sensor incorporates a thin platinum (Pt) film that serves as the hydrogen-sensing layer. Exposure to hydrogen reduces the platinum oxide formed on the surface of this layer, generating tensile stress. This stress actuates the MEMS structure, causing an upward deflection of the membrane and a corresponding decrease in capacitance, thereby enabling hydrogen detection. However, because platinum is readily oxidized in air, oxidation reactions and hydrogen-induced reduction reactions occur simultaneously, partially canceling each other and resulting in reduced sensitivity.

To address this issue, a silicon dioxide (SiO_2) barrier layer was applied to the top surface of the platinum layer to inhibit oxygen diffusion and suppress platinum oxidation. The introduction of this barrier layer effectively mitigates sensitivity degradation and enables stable sensor output even at extremely low hydrogen concentrations.

We fabricated prototype sensors and conducted a demonstration experiment to measure the spatial distribution of hydrogen. The results confirmed that hydrogen generated during the early stages of a fire is transported upward by fire-induced updrafts and accumulates near the ceiling, thereby demonstrating the effectiveness of the proposed sensor.

1.12 Technology for Enhancing Visibility of Microscopic Defects Using Digitally Controlled Illumination



Imaging system equipped with digitally controlled illuminator and example of captured image

Manufacturing industries, including semiconductor and automotive manufacturing, require non-contact, high-speed inspection of microscopic surface defects on production lines to enable pass/fail determination and thereby ensure product quality. However, conventional imaging techniques often fail to detect such defects, particularly those with uneven surface profiles exhibiting submicron-scale height variations, due to insufficient brightness contrast.

To address this issue, Toshiba Corporation has designed a unique optical system that captures the bidirectional reflectance distribution function (BRDF) of opaque surfaces as color variations and has realized an imaging technology called “One-Shot BRDF” that enables instantaneous visualization of microscopic defects. In this optical system, a color filter with concentric color variations is placed at the Fourier plane (focal plane) of the imaging lens to establish a correspondence between light propagation direction and color. By sharpening the color transitions, even slight changes in light direction caused by defects can be detected as color variations. However, the spatial resolution of physical color filters is limited (on the order of several hundred micrometers), necessitating a higher-resolution color filter to capture faint scattered light from nanoscale defects.

To overcome this limitation, we devised a digitally controlled illumination method in which colors are pre-assigned to the direction of illumination light. This approach employs a projection-based color filter in place of a physical color filter, whereby a reduced color filter pattern is projected onto the Fourier plane of the illumination lens using a digital micromirror device (DMD) projector. As a result, the spatial resolution was improved by approximately two orders of magnitude compared to that of physical color filters, enabling faint scattered light from

nanoscale defects to be captured as color variations. Consequently, even nanoscale defects on semiconductor wafers that could not be detected using conventional imaging systems were successfully visualized.

Furthermore, this technology enables instantaneous optimization of the projection-based color filter according to the inspection target, thereby eliminating issues associated with physical color filters, such as temporal degradation and variations in spectral transmission characteristics.

1.13 Source Code Comprehension Support Technology for Infrastructure Systems Software Maintenance

Software used in infrastructure systems typically has a long lifecycle and requires continuous maintenance over decades of operation to accommodate user requests for specification changes and functional enhancements. Such requests are often not anticipated in the initial software design and frequently necessitate extensive modifications to the source code. However, as original software developers may be reassigned or retire over the course of long-term system operation, understanding existing source code entails time- and labor-intensive processes, thereby increasing the need for technologies that support source code comprehension.

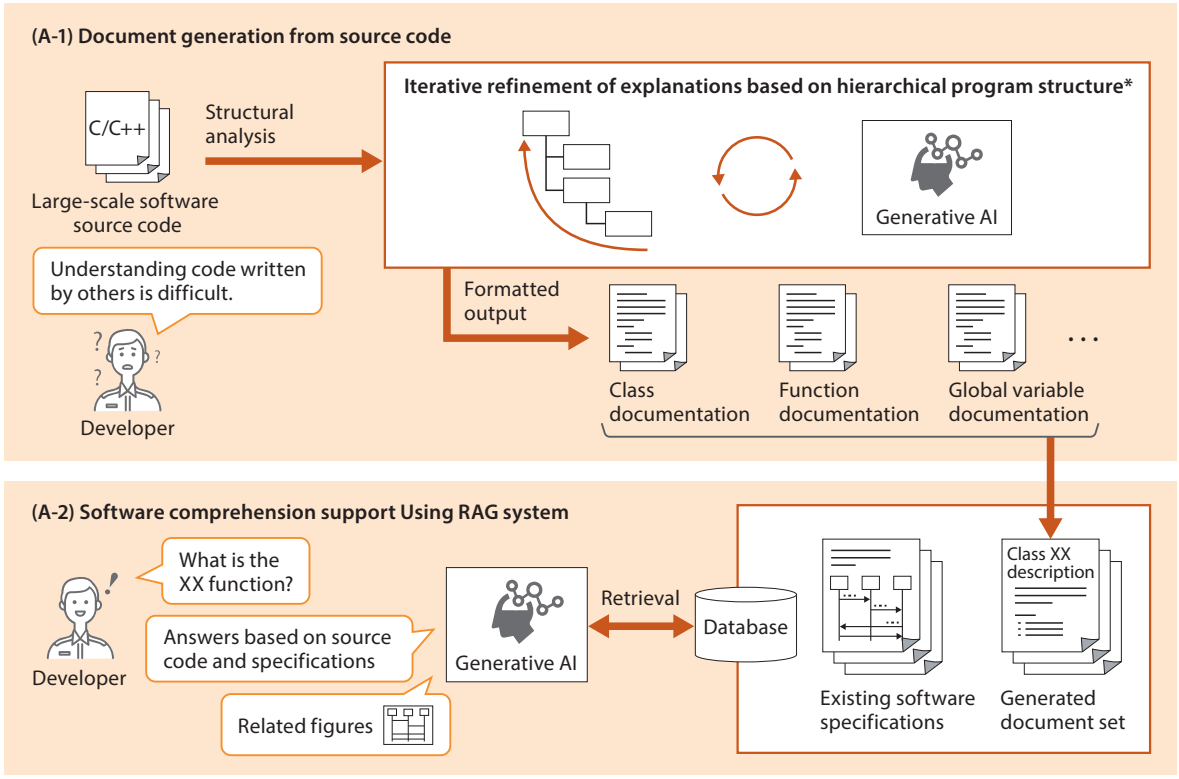
To address this challenge, Toshiba Corporation has developed an AI-powered document generation system that takes source code as input and produces hierarchical, text-based software explanations, ranging from an overview of the entire program to detailed descriptions of specific processing logic. This system enables software developers to quickly grasp the overall program structure and obtain a deeper understanding of the program as needed.

Prior to feeding the code to the AI system, we perform static code analysis to extract structural information such as function arguments, return values, and dependencies between code elements. This process enables accurate descriptions of the code's behavior and its relationships with other components. In addition, the AI system supports global variables, which are commonly found in legacy software designs, particularly in embedded software. To clarify the relationships between global variables and the functions that reference them, dependency-related information is extracted and explanatory text is generated using a unique iterative analysis method. As a result, more comprehensive explanations that capture the overall structure of the code can be generated.

In an actual product development environment, a retrieval-augmented generation (RAG)(*) system has been introduced that uses the AI-generated documents and manually prepared specifications as input. When software developers enter questions about the software, the system retrieves relevant information from these documents and provides answers together with figures and tables, enabling faster and more efficient understanding of the software.

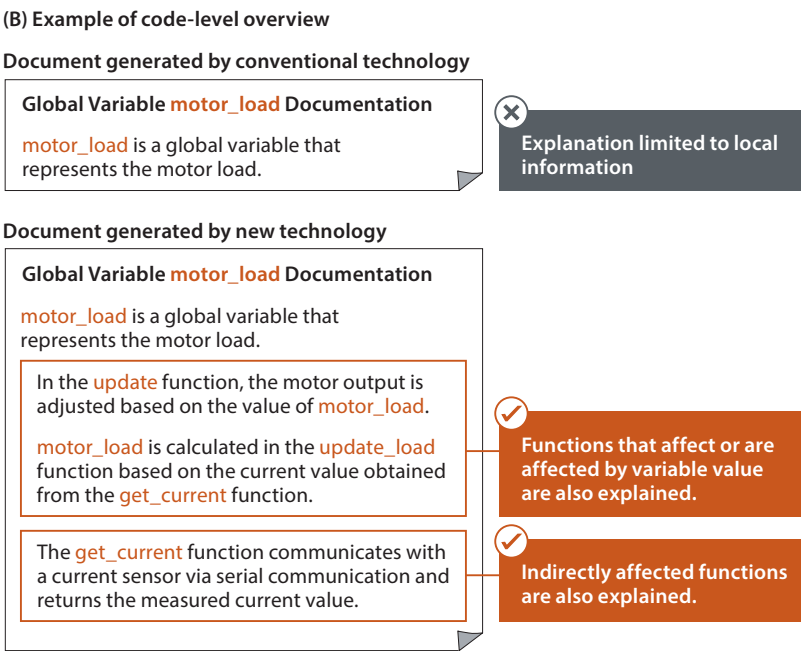
The next step is to expand the range of supported programming languages and enhance the generation of explanatory text by incorporating feedback and requirements from software development teams.

(*) Retrieval-augmented generation (RAG) is a generative AI technique that retrieves relevant documents and generates answers to questions based on the retrieved information.



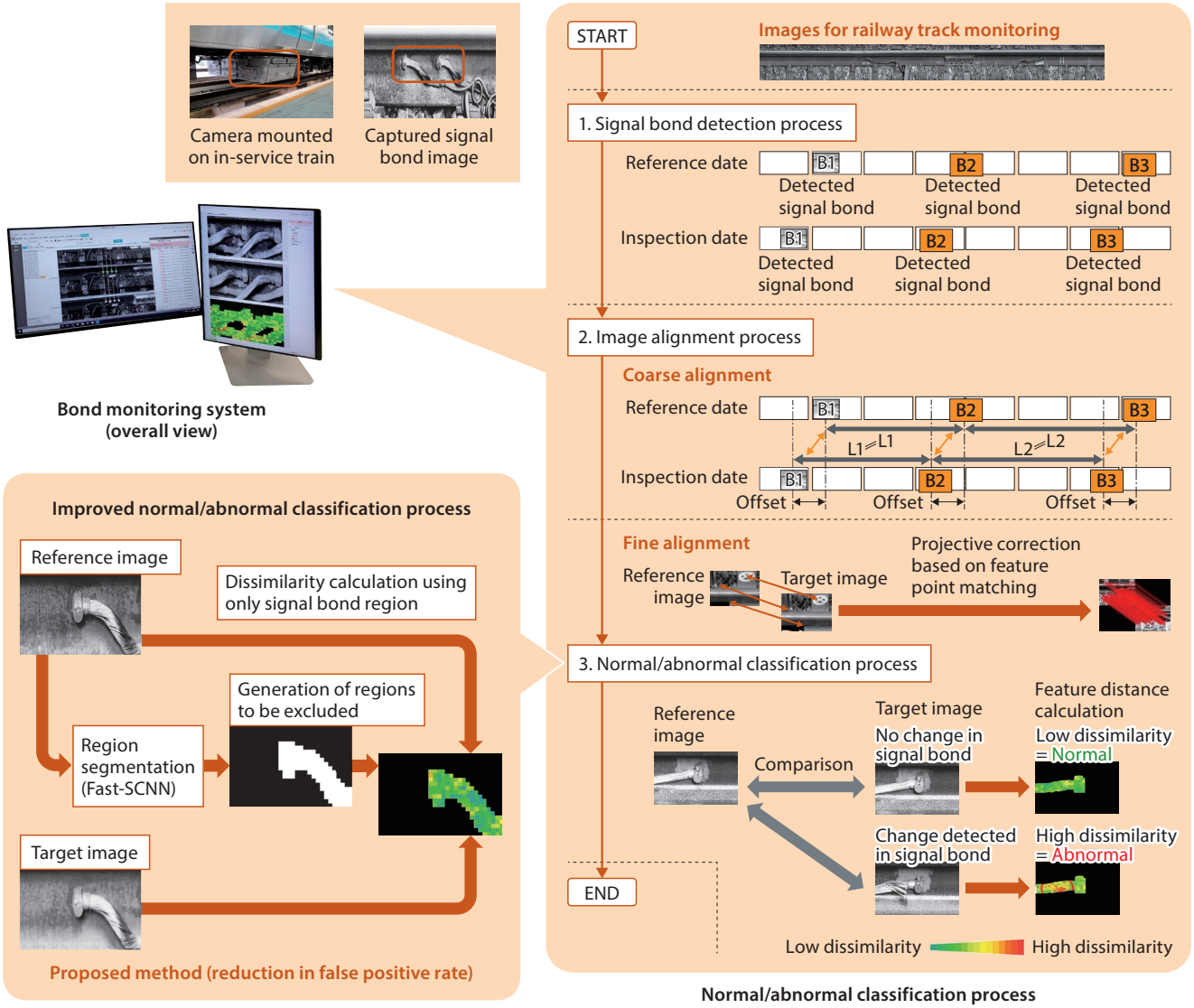
* Dependencies among functions and variables

Document generation and software comprehension support system configuration



Comparison of documents generated using conventional and new methods

1.14 Anomaly Detection Technology for Railway Track Equipment Inspection Using Deep Learning



Bond monitoring system and anomaly detection algorithm overview

Railway tracks are equipped with track-circuit signal bonds that electrically connect rails and signaling devices. Abnormalities, such as the detachment of these signal bonds, can disrupt train operations. However, because these components are widely distributed along railway lines and are primarily inspected at night, the inspection process imposes a significant burden on inspectors, necessitating more efficient inspection methods.

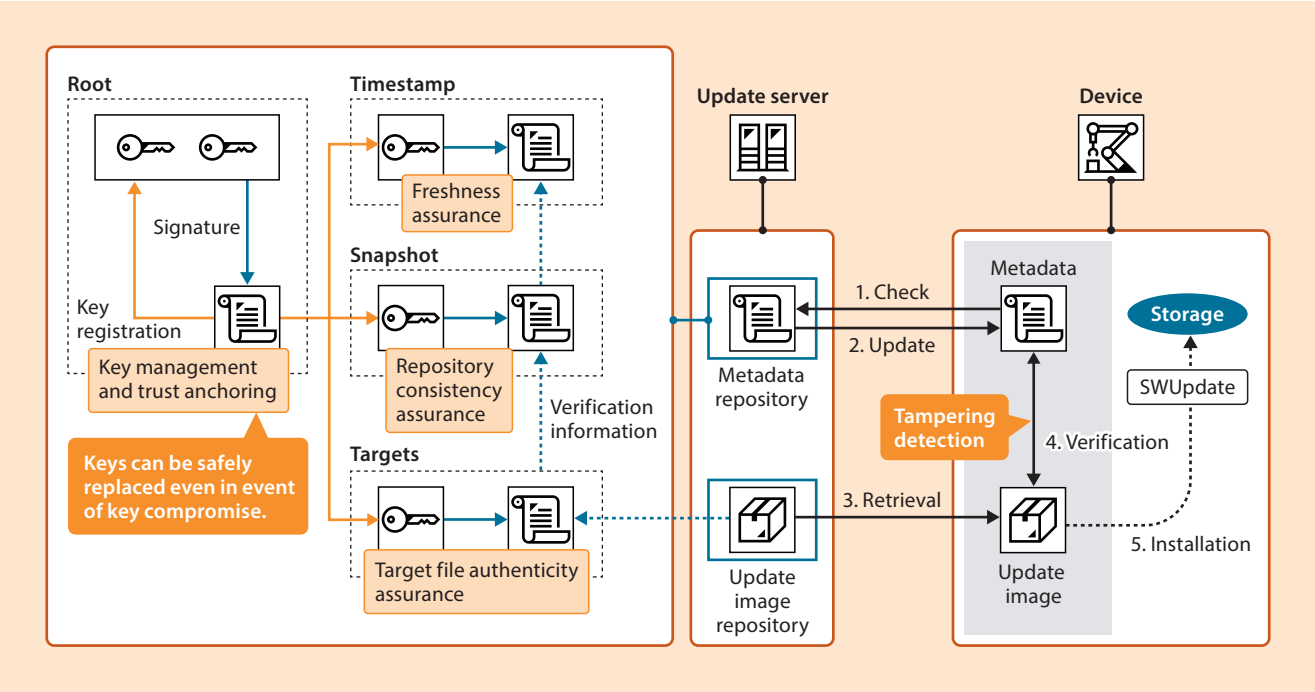
To address this issue, Toshiba Corporation developed a signal bond monitoring system that automatically detects defective components in images captured by cameras mounted on in-service trains. The system has been deployed by railway operators since 2022. However, a trial conducted in 2020 revealed that the false positive rate—defined as the probability of incorrectly classifying normal signal bonds as abnormal—exceeded 20%.

Consequently, we improved the normal/abnormal classification process. Analysis revealed that approximately 70% of false positives were attributable to variations in appearance outside the signal bond region. To address this issue, we introduced a method that extracts only the signal bond region from camera images prior to anomaly detection. For this purpose, we adopted Fast-SCNN (Fast Segmentation Convolutional Neural Network), a deep learning-based semantic segmentation method developed by Cambridge Research Laboratory of Toshiba Europe Ltd. Fast-SCNN significantly reduces the manual effort required to mask regions to be excluded from classification by automatically extracting signal bond regions from reference images. Dissimilarity is then calculated exclusively within the extracted regions, resulting in a substantial reduction in the false positive rate.

In addition, automatic signal bond position detection had previously relied on a method combining classical machine learning techniques. However, as the number of railway lines subject to inspection increased, concerns arose about a decline in detection performance. To address this issue, we introduced an improved object detection model based on YOLOX (You Only Look Once X), in which detection accuracy is enhanced through the integration of multiple feature layers. This approach reduces spurious detections and enables flexible adaptation to variations in equipment types and environmental conditions through model retraining alone, thereby simplifying maintenance.

Since January 2025, the improved bond monitoring system has been deployed across 26 railway lines in the Tokyo metropolitan area. Further expansion to high-speed railways is being considered.

1.15 TUF™-Compliant Secure Remote Software Update Mechanism for Embedded Devices



Update verification architecture using The Update Framework (TUF) metadata

Attack type	Features available only with SWUpdate	When using TUF™
1. Arbitrary installation attack	○	○
2. Drop-request attack	×	○
3. Freeze attack	×	○
4. Fast-forward attack	○	○
5. Rollback attack	○	○
6. Endless data attack	○	○
7. Key compromise	×	○

○ : Supported ×: Not supported

Benchmarking results against known cyberattacks

In recent years, embedded devices, such as Internet of Things (IoT) products and industrial equipment, have required continuous software updates even after shipment, making it increasingly important to ensure update security and maintain reliability over long-term operation. Traditionally, a certain level of security has been achieved through the verification of signed images. However, challenges have remained in the management of signing keys and in recovery in the event of a repository compromise.

To address these challenges, Toshiba Corporation has developed a technology that enables secure and continuous software updates by incorporating The Update Framework™ (TUF™)—a specification designed to enhance the trustworthiness of software distribution—into an update mechanism based on the open-source software SWUpdate.

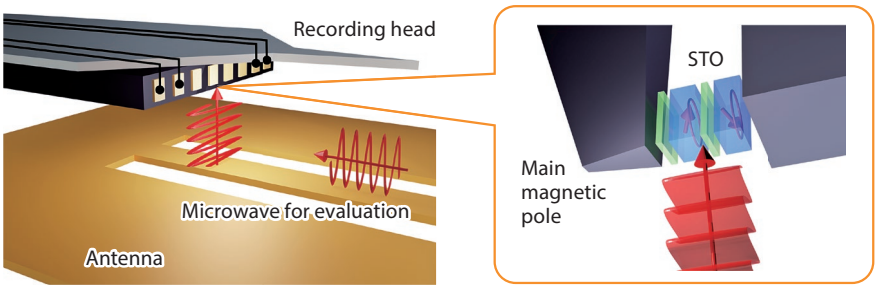
SWUpdate provides high availability through an A/B update method that prepares and switches between two update partitions, as well as efficient distribution through delta updates. In addition to these advantages, the new technology integrates a metadata signing and verification mechanism based on the TUF™ specification. TUF™ is designed such that (1) root metadata manages public keys as the anchor of trust; (2) targets metadata guarantees the authenticity of distributed files and enables the detection of tampering; (3) snapshot metadata ensures repository consistency; and (4) timestamp metadata verifies freshness to prevent the misuse of outdated information. As a result, the application of update images tampered with during transmission is prevented, and updates can continue while maintaining reliability even in the event of signing key or repository compromise. Furthermore, TUF™ does not require encrypted communication (TLS: Transport Layer Security), enabling update processing with integrity verification even on embedded devices where TLS is unavailable.

Verification tests using actual hardware confirmed that the update flow incorporating TUF™ metadata functions correctly and that updates can safely continue even in scenarios involving signing-key rotation. In addition, it was confirmed that when a tampered update image was distributed, signature verification failed as expected, thereby preventing the application of unauthorized software.

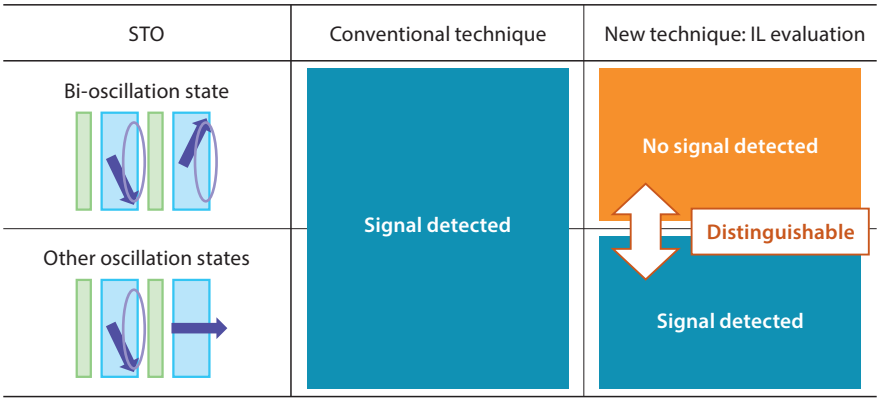
Going forward, we will continue to enhance a secure and sustainable software update platform leveraging TUF™ and expand its adoption in domains requiring long-term operation, including manufacturing industry and social infrastructure systems.

The Update Framework and TUF are the trademarks of The Linux Foundation in the United States and/or other countries.

1.16 Injection Locking Evaluation Technique for Spin-Torque Oscillators Used in MAS-MAMR for Nearline HDD Applications



Schematic of injection locking evaluation for spin-torque oscillator (STO)



Overview of evaluation results

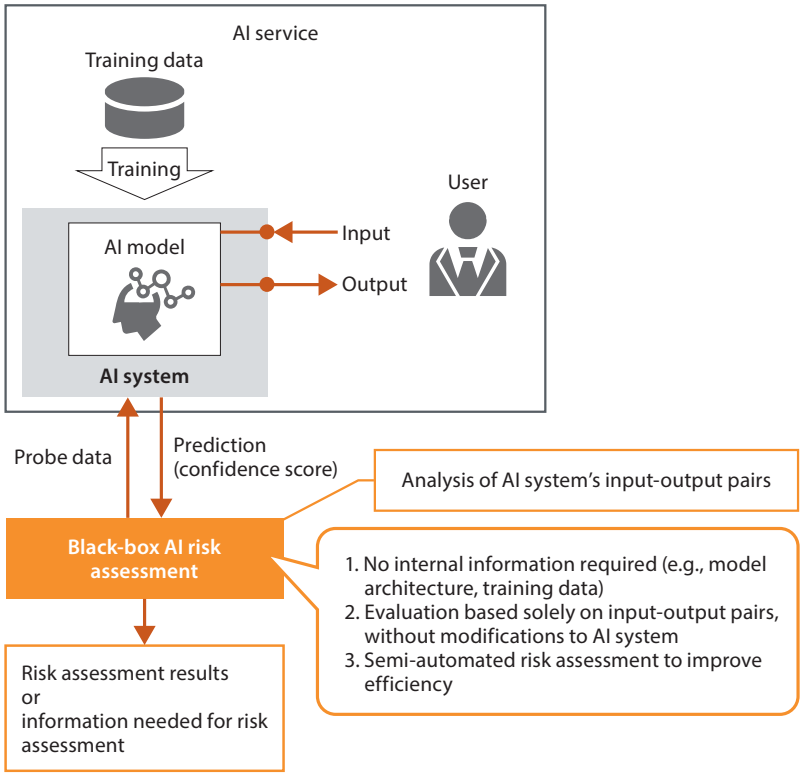
Microwave-assisted switching-microwave-assisted magnetic recording (MAS-MAMR), a next-generation recording technology for hard disk drives (HDDs), utilizes microwaves generated by a spin-torque oscillator (STO). Achieving high-density recording requires the bi-oscillation state in which two magnetic layers within the STO oscillate in unison. However, conventional evaluation techniques have been unable to detect the oscillation state of an STO integrated into a recording head.

To address this issue, Toshiba Corporation has developed an injection-locking (IL) evaluation technique that applies an external microwave to the STO and measures the IL signal associated with the synchronization phenomenon. The IL signal is absent in the bi-oscillation state but appears in other oscillation states, enabling identification of the STO oscillation state.

The IL evaluation technique enhances understanding of STO behavior and helps improve the MAS-MAMR architecture. It also contributes to the development of high-capacity nearline HDDs for data centers, for which demand continues to grow due to advances in technologies such as generative AI.

This research was conducted in collaboration with the National Institute for Materials Science (NIMS) of Japan.

1.17 Risk Assessment Technology for AI Systems



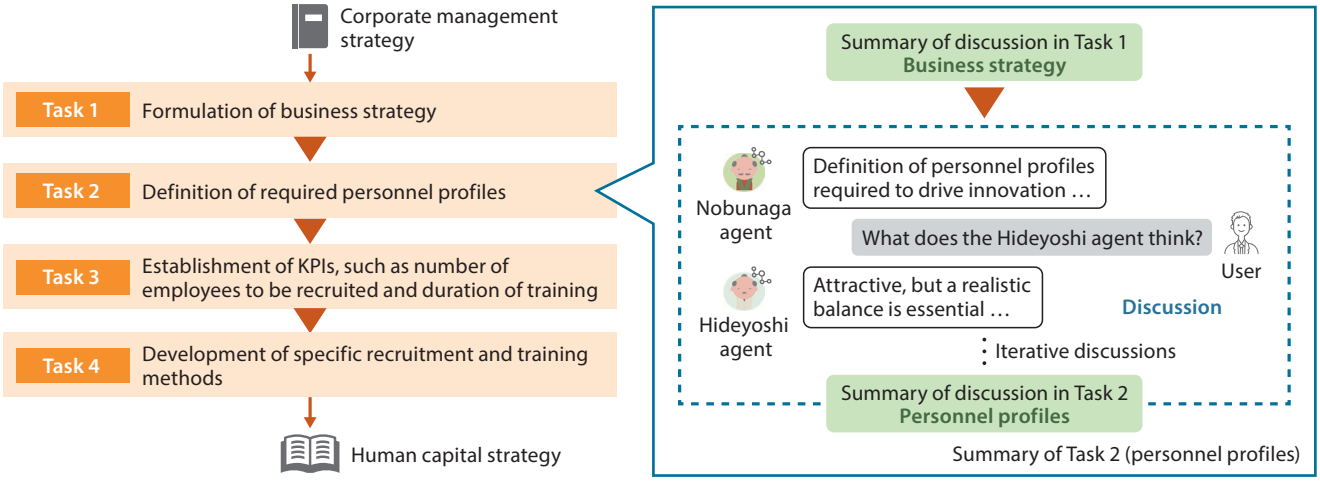
Overview of risk assessment technology for AI systems

With the widespread adoption of AI systems, addressing risks arising from AI-specific threats has become an increasingly important challenge. These threats include adversarial attacks, in which carefully crafted input perturbations (e.g., adversarial noise or patches) induce system malfunctions; data bias, which leads to discriminatory outputs due to imbalanced training data; and model extraction attacks, in which an attacker repeatedly queries a system to replicate its model, potentially resulting in the leakage of confidential know-how. Because such threats can arise at various stages, including development (e.g., model training and retraining) and operation, AI service providers are required to establish mechanisms for continuous risk assessment throughout the entire service lifecycle, from development through operation.

To address this need, Toshiba Corporation is investigating a black-box approach to AI risk assessment that evaluates AI systems solely based on input-output behavior, without requiring modifications to deployed systems or access to internal information such as model architecture or training data. Currently, we are developing a fundamental technique for detecting race- or gender-related unfairness in AI systems incorporating face recognition models.

We will expand the scope of target AI services and evaluation items and establish operational guidelines for interpreting outputs and translating the findings to risk management actions, thereby advancing a practical toolset that supports safe and trustworthy use of AI.

1.18 Human Capital Strategy Planning Support System Using Multi-Agent AI Technology



Overview of human capital strategy planning support system

In the face of labor shortages caused by a declining workforce and shifting market conditions, the development of sophisticated human capital strategies aligned with business objectives has become essential for the sustainable growth of enterprises. However, conventional human capital strategy planning often lacks objectivity and consistency due to its reliance on subjective judgment and insufficient organizational frameworks. As a result, many enterprises face difficulties in implementing effective human capital strategies that are properly aligned with their business strategies.

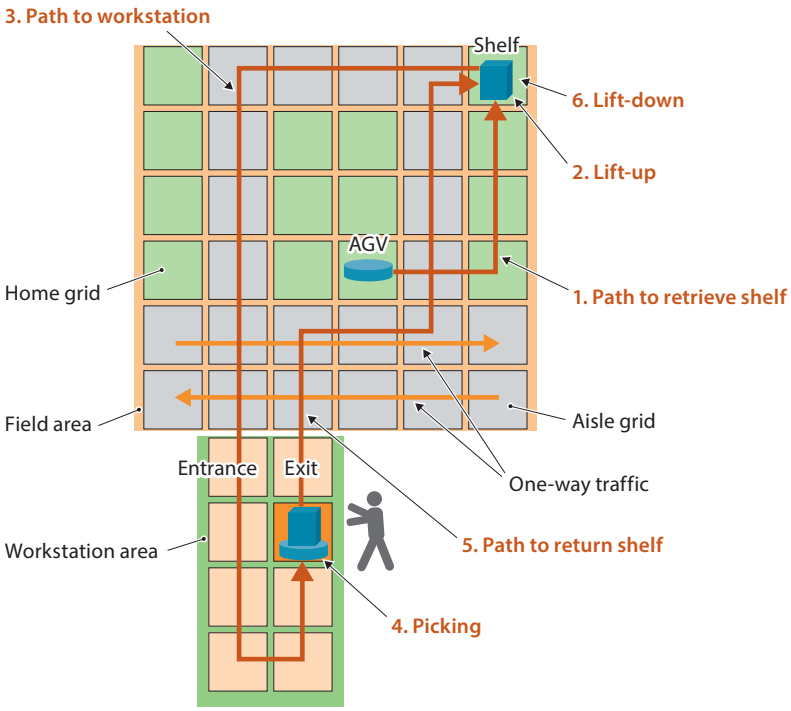
To address this challenge, Toshiba Corporation has developed a human capital strategy planning support system based on multi-agent AI technology(*), in which each AI agent is assigned a distinct persona representing different roles and perspectives and engages in collaborative discussions. Through these interactions, the system leverages collective intelligence to support the development of multifaceted and creative strategies that are difficult to achieve with a single AI agent.

The system accepts a corporate management strategy as input and sequentially executes four tasks: (1) formulation of business strategies, (2) definition of required personnel profiles, (3) establishment of key performance indicators (KPIs), such as the number of new employees to be recruited and the duration of training, and (4) development of specific recruitment and training methods.

In addition, users can participate in the discussions and incorporate their questions and feedback, which are subsequently reflected in deliberations among the AI agents. The system provides advanced support for human capital strategy planning that is closely aligned with business strategies.

(*) An AI agent is defined as an AI system that autonomously makes decisions and takes actions to achieve a given task.

1.19 Optimal Path Planning for Multiple AGVs Designed for Real-World Operations in Large-Scale, High-Density Warehouses



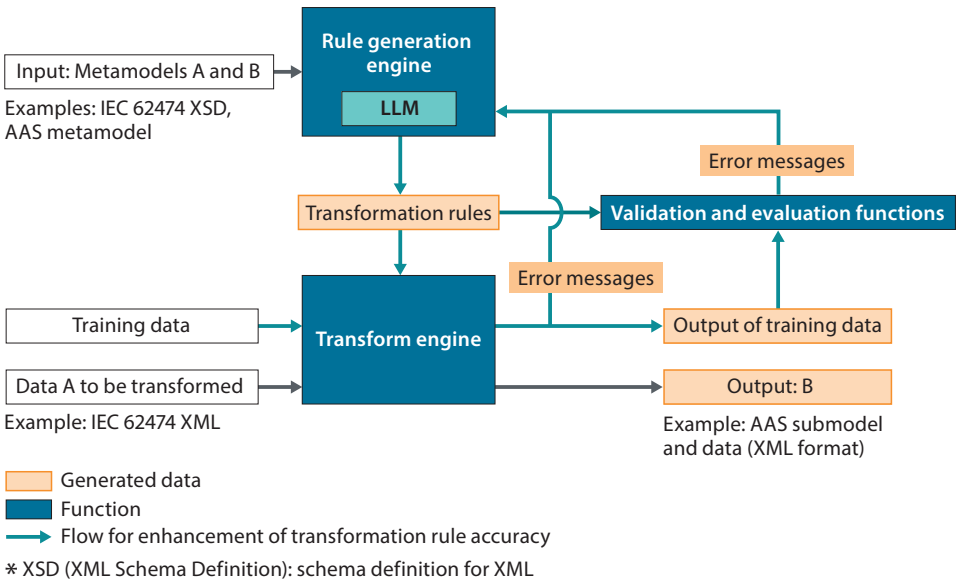
AGV path planning and shelf handling (retrieval, transport, and return) processes

Against the backdrop of the rapid growth of the e-commerce (EC) market and a persistent labor shortage, automated guided vehicles (AGVs) are attracting increasing attention as a core technology for warehouse automation. However, when operating hundreds of AGVs simultaneously in large and complex warehouse environments, conventional approaches face significant challenges in efficiently computing optimal paths while avoiding collisions and congestion. In particular, computational costs increase dramatically with the number of AGVs, thereby limiting the number of AGVs that can be practically deployed.

To address these issues, Toshiba Corporation has developed a method based on multi-agent pathfinding (MAPF) technology that dynamically adjusts priorities among AGVs and performs rerouting calculations only within the necessary scope. This approach significantly reduces computational load while enabling flexible path planning that takes into account real-world warehouse constraints, such as shelf layouts and one-way traffic rules. Simulations involving the simultaneous operation of 200 AGVs demonstrated that the new method reduces travel distances without collisions and significantly improves computation time.

Next, we aim to realize next-generation smart logistics systems that achieve both high energy efficiency and throughput by combining further computational acceleration through parallel processing with congestion prediction based on deep learning.

1.20 LLM-Based Standard Data Generation Technology



Framework for data interoperability using LLMs

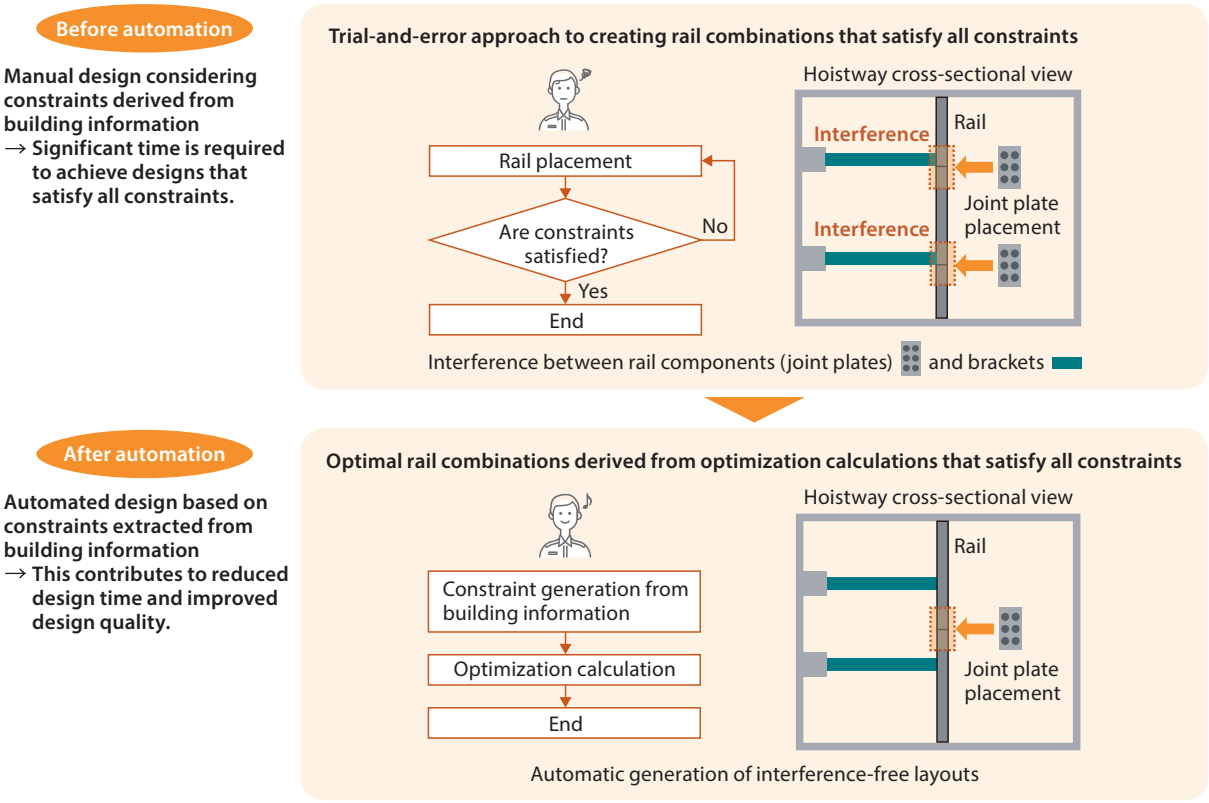
Toshiba Corporation has developed a technology for the automatic generation of standardized data using large language models (LLMs), enabling efficient and highly accurate data interoperability among heterogeneous systems—a process that has traditionally required substantial manual effort and cost. This technology employs a rule generation engine to create data transformation rules based on metamodel information, including schemas, formats, and constraints. The transformation rules are then iteratively refined to enhance accuracy by feeding back error messages from a transformation engine—utilizing training data—as well as outputs from validation and evaluation functions into the LLM. The resulting transformation rules are applied to convert real-world operational data into standardized formats, thereby ensuring transparency and explainability.

For the transformation from the format specified in International Electrotechnical Commission (IEC) 62474—an international standard for material declarations for products—into the Asset Administration Shell (AAS)(∗1) model, the proposed technology achieves error-free generation of AAS data with both semantic and syntactic consistency by leveraging Extensible Stylesheet Language Transformations (XSLT)(∗2) in combination with external tools. This capability enables the automatic generation of standardized data for Digital Product Passports (DPPs), including information on substances contained in products and carbon dioxide emissions. We are advancing the technology toward practical implementation to support the realization of a sustainable society.

(∗1) The Asset Administration Shell (AAS) is an international standard that specifies metamodel and format for describing product lifecycle data.

(∗2) Extensible Stylesheet Language Transformations (XSLT) is a language based on Extensible Markup Language (XML) and is used to transform XML documents into other formats.

1.21 Automated Layout Technology and Design Workflow for Elevator Guide Rails



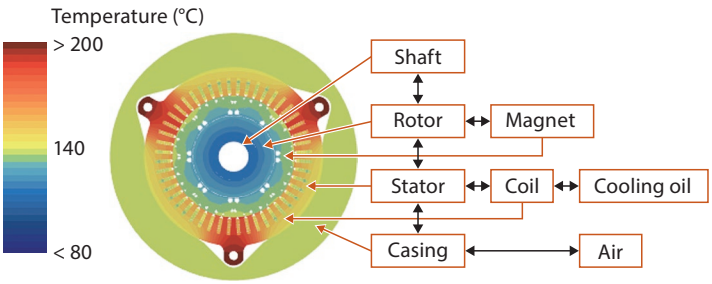
Automated guide rail and bracket layout technology

In elevator planning and design, guide rails must be positioned so as not to interfere with other equipment or structural components. If any portion of a guide rail fails to satisfy the design constraints, the entire layout must be revised. Conventional trial-and-error processes have often resulted in iterative rework, requiring a considerable amount of time. Furthermore, reliance on the experience and skills of individual designers presents challenges in maintaining consistent design quality and optimizing costs.

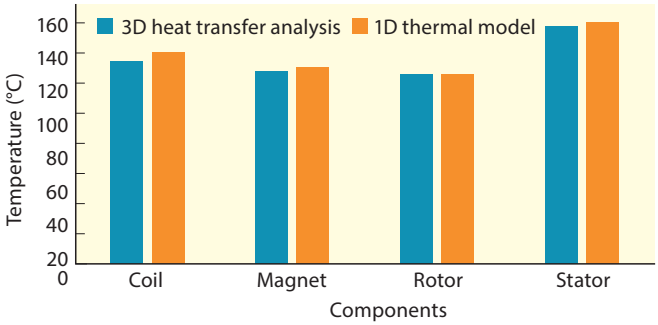
To address these challenges, Toshiba Corporation has developed an automated layout technology for guide rails and the brackets used to secure them to the hoistway, based on hoistway geometry data. This technology performs optimization calculations to minimize total cost while satisfying multiple constraints, including the prevention of interference between rail joint plates and brackets.

Demonstration experiments confirmed the practicality of the proposed technology, with feasible design values obtained for most of the buildings evaluated. It was also confirmed that the technology contributes to reduced design time. These results demonstrate that the proposed technology improves both the efficiency and quality of elevator planning and design.

1.22 High-Accuracy 1D Thermal Model for Motor MBD Systems



Temperature distribution obtained with 3D thermal simulation and overview of 1D model



Comparison of component temperatures obtained with 3D simulation and 1D model

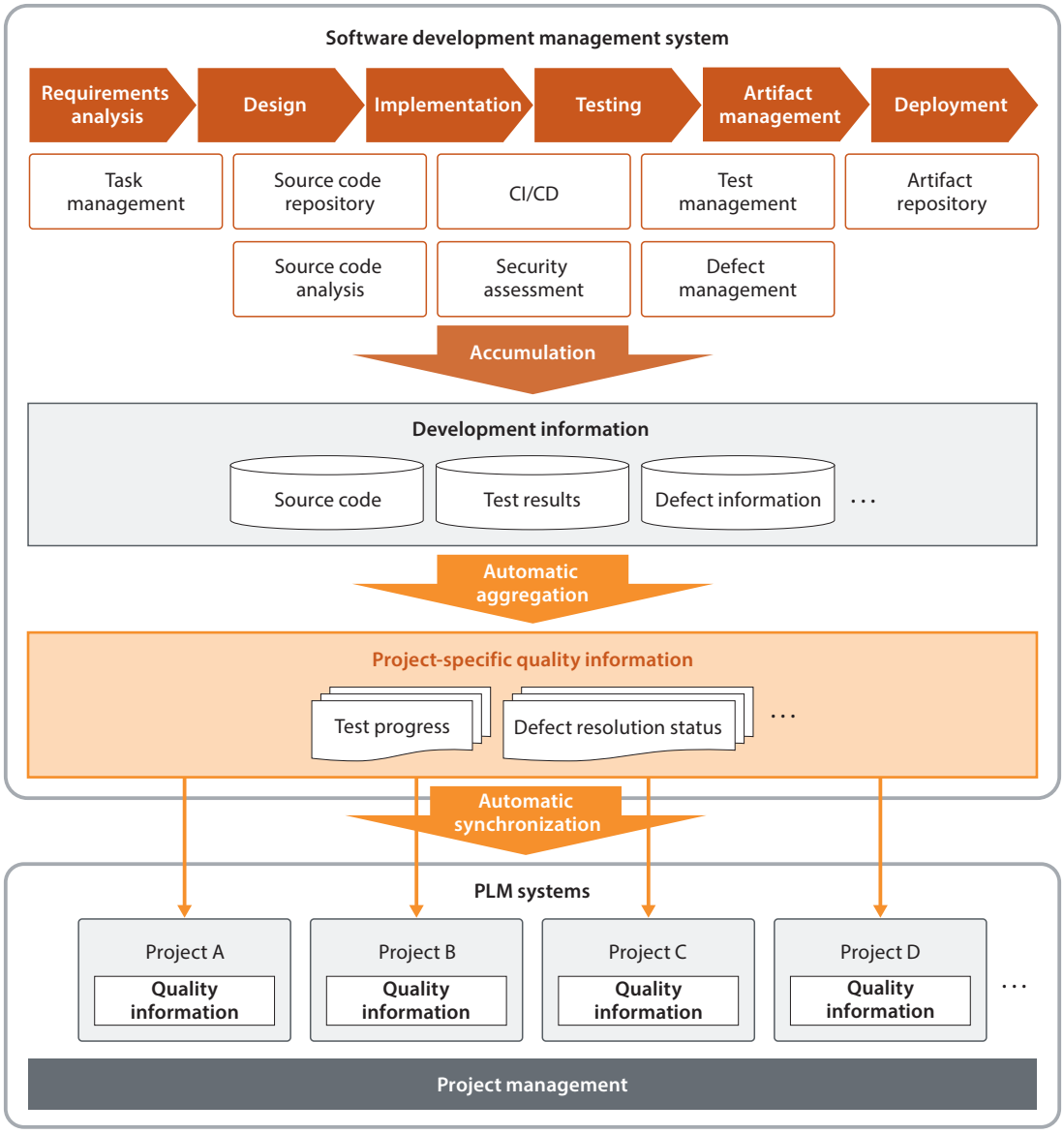
To shorten the development period for motor applications, Toshiba Corporation has been developing a model-based development (MBD) system that enables the prediction of motor characteristics prior to prototyping. Improving the accuracy of this system requires accurate evaluation of the temperature distribution within the motor, as well as the use of material properties that account for temperature dependence.

In this study, we developed a one-dimensional (1D) thermal model capable of accurately evaluating the temperature distribution in oil-cooled motors. In the radial direction, the model is divided into elements representing the shaft, rotor, stator, and casing, with permanent magnets embedded in the rotor and coils embedded in the stator. In the axial direction, the model is divided into eight segments. Heat generation conditions are assigned to the coils, magnets, rotor, and stator, while heat transfer conditions simulating oil cooling are applied to the coil ends. In addition, thermal resistances are introduced between adjacent elements, enabling evaluation of the temperature distribution.

To verify the accuracy of the 1D thermal model, three-dimensional (3D) heat transfer analysis was conducted, and the resulting temperature distributions were compared under six different heat generation conditions. The results indicate that the temperatures of the major components are predicted within an accuracy of ±6°C under all conditions.

In future work, we will further improve model accuracy by incorporating circumferential temperature distributions, thereby contributing to the advancement of motor MBD systems.

1.23 Enhancing Efficiency of Quality Management Through Integration of Software Development Management and PLM Systems



CI/CD: continual integration and continuous delivery/deployment

Integration of software development management and PLM system

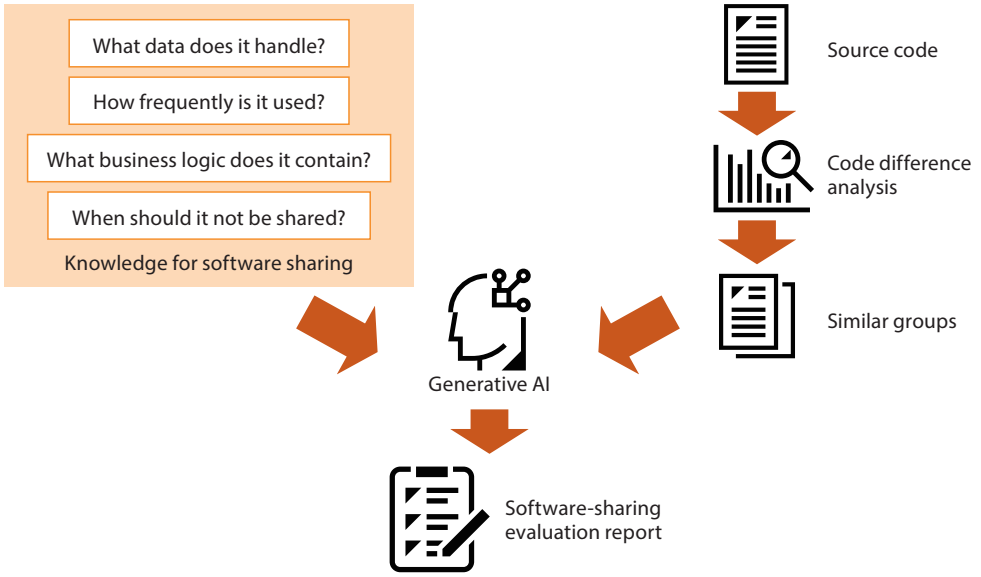
In 2013, the Toshiba Group established a software development management system that is currently used by more than 20 000 engineers across over 41 group companies in Japan and abroad. While this system has contributed to the standardization of quality and project progress management, a significant portion of the analysis and aggregation of software development data relies on manual operations, posing a challenge to improving operational efficiency.

To address this issue, we introduced a feature to integrate the software development management system with product lifecycle management (PLM) systems in April 2025. Development

data accumulated daily in the software development management system—such as source code, test results, and defect information—are automatically collected in batches during nighttime processing and aggregated into project-level metrics, including test progress and defect resolution status. The aggregated results are then automatically reflected in the PLM system. Although nighttime processing is the default for handling several thousand projects, the system also supports on-demand updates at the individual project level when immediate data synchronization is required.

The integration of the two systems enables up-to-date quality-related information in the PLM system—previously compiled manually by project members—to be referenced and analyzed on demand. As a result, this integration is expected to further improve the efficiency of quality management and accelerate decision-making.

1.24 Technology for Identifying Shareable Software Components to Promote Reuse



Overview of software reuse evaluation method

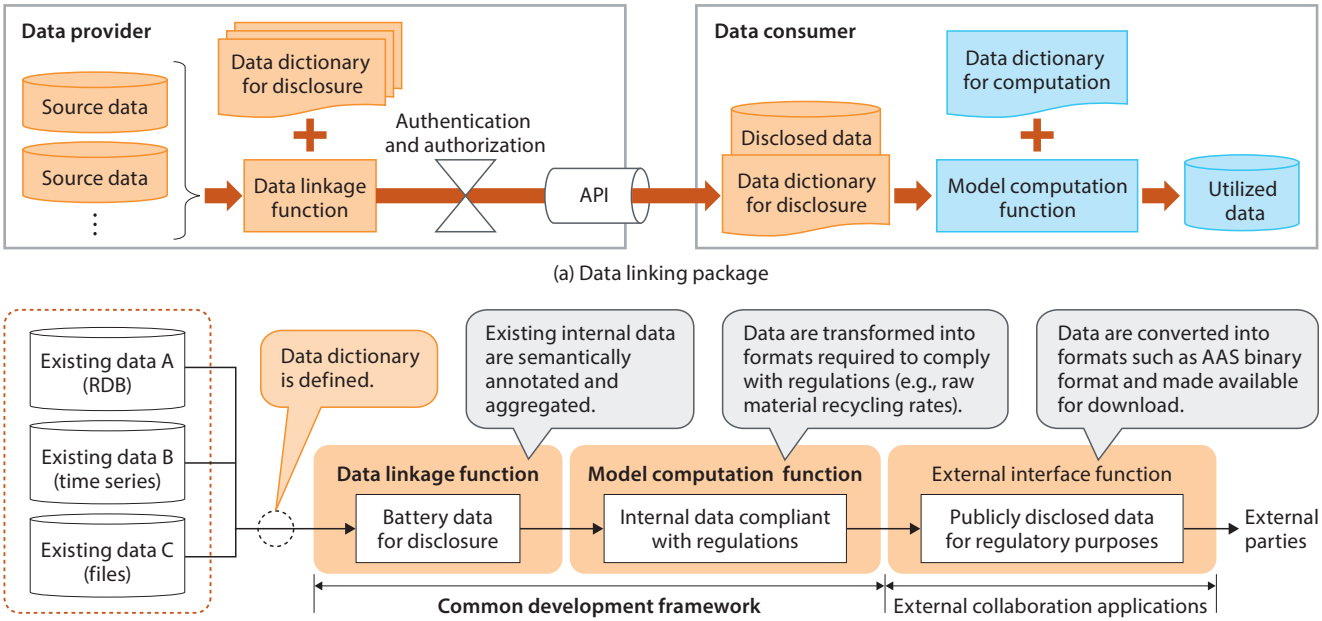
When multiple variants of a software product are developed, implementing similar functionalities independently for each variant tends to be inefficient. Software product line (SPL) engineering, originally developed at Carnegie Mellon University, improves efficiency by enabling the reuse of software components across product variants. However, as codebases grow in size, identifying software components suitable for shared use becomes increasingly challenging.

To address this challenge, Toshiba Corporation proposes a method for rapidly identifying candidates for shared use by combining source code difference analysis with automated evaluation using generative AI. Conventional source code difference analysis can efficiently process large codebases but is unable to assess semantic similarity. In contrast, generative AI can account for code semantics and implementation intent; however, its accuracy decreases when applied directly to large-scale codebase analysis.

The proposed method combines the advantages of both techniques. Source code difference analysis is first employed to efficiently group similar code fragments, and generative AI is then used to evaluate each group based on practical criteria for software reuse, including the data handled by the code, expected usage frequency, the roles of business logic, and conditions under which reuse may be inappropriate. The method also generates a report to support engineers in selecting software components for reuse.

When applied to a software system of approximately 400 000 lines of code, the proposed method automatically identified candidates for reuse corresponding to 15% of the codebase in five hours. In future work, we will expand the application of this method to software systems on the order of one million lines of code and further improve the accuracy of similar code retrieval.

1.25 Data Linkage Package: Common Development Framework for Enterprise Data Interoperability



RDB: relational database AAS: Asset Administration Shell

Overview of data linking package and application example

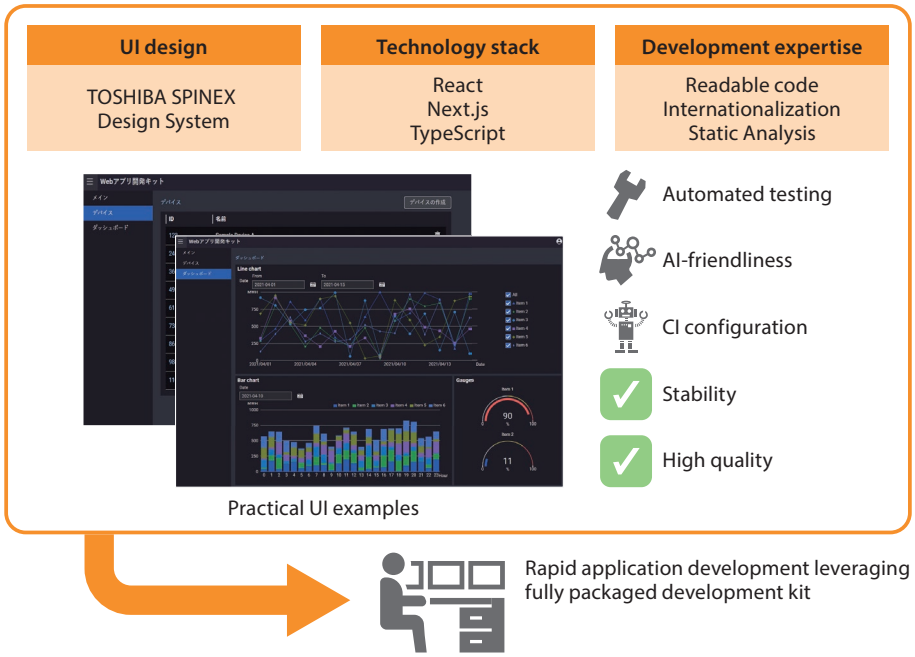
Toshiba Corporation has developed a data linkage package that enables effective utilization of data dispersed across an organization. This package consists of two main components: (1) a data linkage function, which wraps existing datasets with a data dictionary compliant with IEC standards and makes them available as APIs following authentication and authorization; and (2) a model computation function, which enables data consumers to perform model transformations—such as unit conversion and statistical processing—according to their specific purposes.

This approach enables loose coupling between data providers and data consumers, thereby facilitating versatile, multi-purpose data utilization while allowing data to remain distributed. Furthermore, by modifying data dictionary definitions and transformation rules, it becomes possible to rapidly accommodate purpose-specific usage requirements without requiring software modification.

The data linkage package is provided as a shared asset across the Toshiba Group in the form of an npm package, facilitating its integration into existing systems. The package is being applied to a battery data interoperability platform supporting digital battery passports, which require flexible responses to frequent regulatory additions and changes. Going forward, we will further leverage the package to enable interoperability among multiple applications and deploy it as a common interface for creating new value.

npm is a registered trademark of GitHub, Inc., in the United States and/or other countries.

1.26 Ready-to-Use Starter Kit for Front-End Web Application Development



Overview of web front-end app starter kit usage

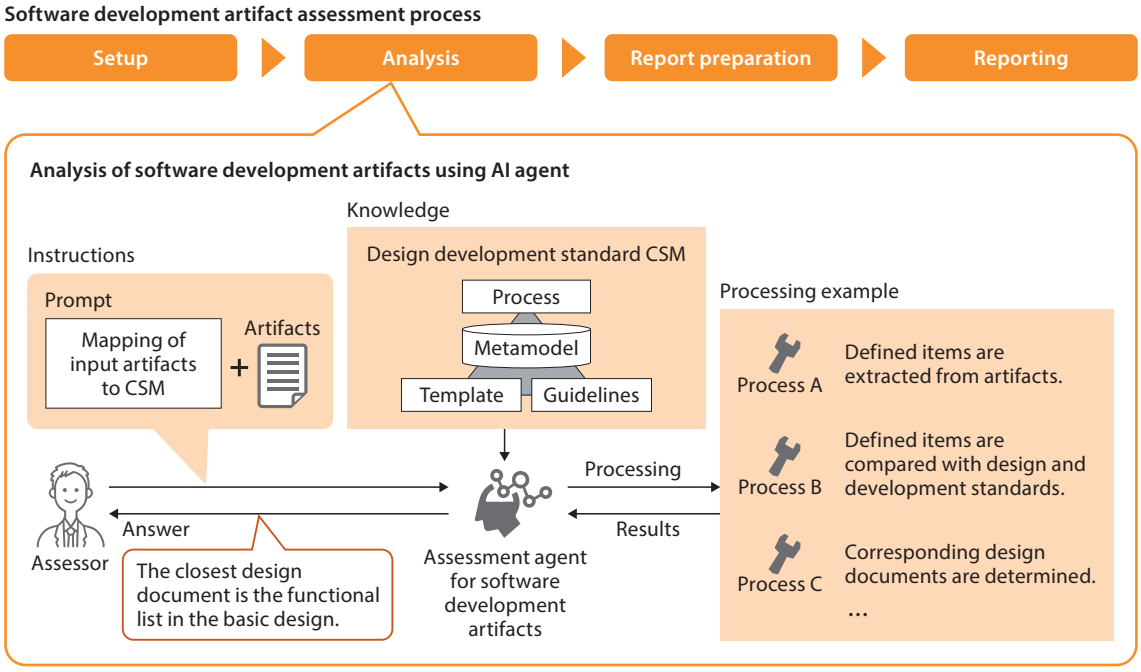
Nowadays, system development projects place increasing emphasis on the early delivery of user experience and on quality assurance from the initial phases. Against this backdrop, Toshiba Corporation has developed a starter kit that streamlines the early phases of front-end application development, enabling developers to focus their efforts on implementing user interface (UI) and business logic directly linked to customer value.

This kit provides practical UI samples and automated tests based on an industry-standard technology stack. It facilitates a smooth transition from prototyping to full-scale development, while its standardized implementation patterns and testing strategies ensure consistent quality assurance from the outset. By establishing these foundations early, development teams can avoid iterative rework and maintain consistency as the project progresses.

Furthermore, by systematizing development techniques that leverage generative AI agents, the kit significantly reduces the effort required for design and implementation while accelerating feature enhancements and bug fixes, thereby improving overall development agility. As front-end web development can proceed without waiting for back-end completion, development teams can obtain early feedback from users and stakeholders, which in turn contributes to improved efficiency across the entire project lifecycle.

In this way, the starter kit enables the sustainable delivery of high-quality development with minimal effort. Over the long term, it is expected to deliver substantial reductions in development costs while supporting continuous improvement and rapid responses to changing requirements.

1.27 Efficient Approach to Assessing Software Development Processes and Artifacts



CSM: Common Style Methodology

Overview of software development artifact assessment agent

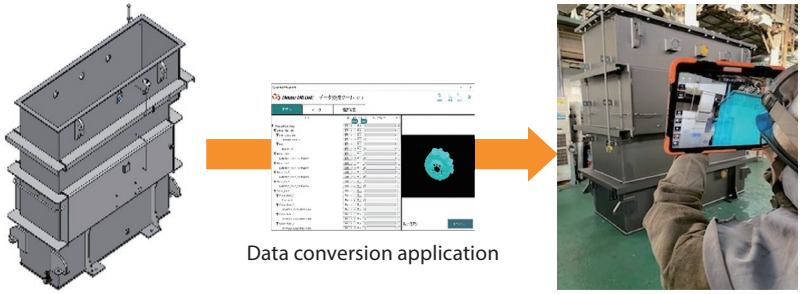
Software process improvement (SPI) activities involve the assessment of software development processes and artifacts to understand development practices and formulate improvement plans. However, these activities generally require manual assessment by experts with in-depth knowledge of software development standards, resulting in significant time and cost overhead.

In this context, Toshiba Corporation has developed an assessment agent for software development artifacts by integrating the Toshiba Group's software development standards with generative AI technologies. Focusing on the requirements definition and design phases of the software development process, the agent automatically evaluates the conformity of software development artifacts—such as requirements specifications and basic design documents—to the relevant development standards.

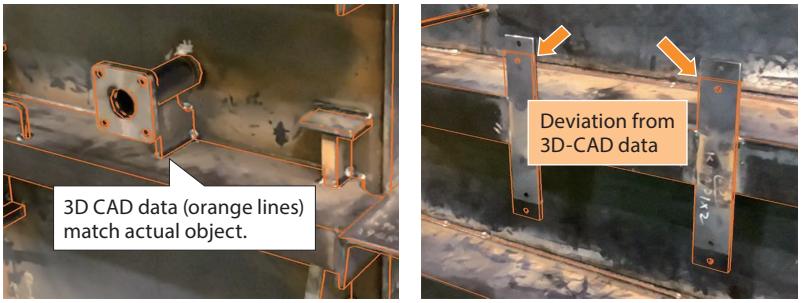
An experiment showed that approximately 80% of the assessment results produced by the agent were consistent with those generated by human assessors. This approach enables a human-in-the-loop assessment process in which assessors review and refine AI-generated results, thereby reducing manual effort while maintaining assessment quality.

The next step is to deploy the agent in real-world projects to further reduce the effort required for assessing software development processes and artifacts.

1.28 Improving Visual Inspection Quality in Assembly and Welding Processes Using Mixed Reality Technology



Overview of MR inspection

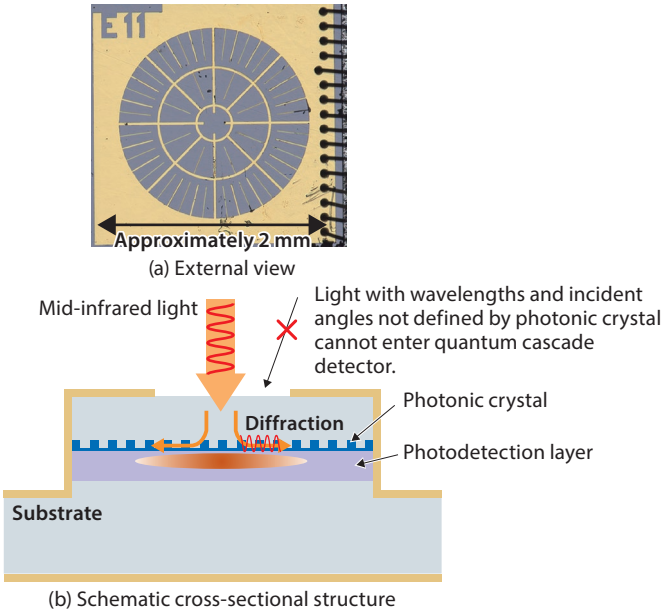


Example of MR inspection results

In assembly and welding processes, visual inspection is conducted to detect missing components as well as errors in the position and orientation of parts. As a countermeasure against missed defects, double-checking by experienced personnel is often employed. However, completely eliminating missed defects has proven difficult, highlighting the inherent limitations in human-dependent methods. In addition, reducing inspection man-hours per unit and minimizing reliance on individual operator skill have become key challenges.

To address these issues, Toshiba Corporation has developed Meister MR Link, a 3D computer-aided design (CAD) data utilization solution for manufacturing sites. Visual inspection using mixed reality (MR), in which a 3D model is overlaid onto the actual product using a tablet device, was applied to the manufacturing process of transformer tanks to evaluate its effectiveness. In practical operation, aligning the 3D model with the physical object was time-consuming; therefore, inspection efficiency was improved by presetting the initial inspection viewpoint to the default position of the 3D model. As a result, inspection errors can be reliably detected regardless of the operator's skill level, achieving zero defect outflow to downstream processes over a continuous eight-month period following implementation. Furthermore, inspection man-hours per unit were reduced by approximately 80%, significantly improving inspection efficiency. In addition, inspection results can now be recorded as photographs, contributing to enhanced traceability.

1.29 Mid-Infrared Surface-Illuminated Quantum Cascade Detector with Thermal Noise Reduction Capability



Quantum cascade detector: External view (top) and schematic cross-sectional structure (bottom)

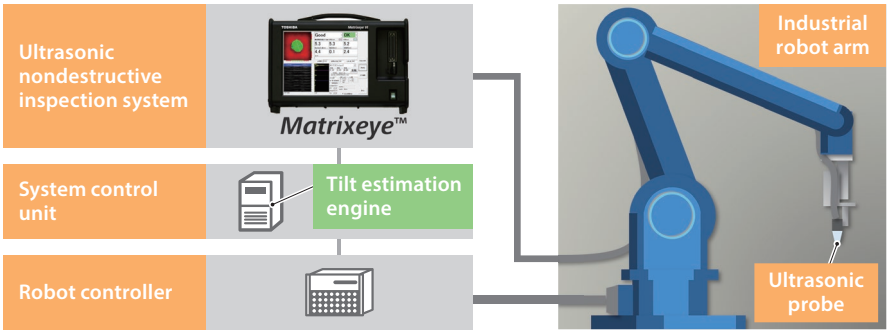
The mid-infrared spectral region contains fundamental vibrational absorption bands of various molecules and is therefore widely used in gas sensing applications to estimate gas type and concentration through spectroscopic measurements. Accordingly, highly sensitive photodetectors have been developed for this spectral region. However, because conventional mercury cadmium telluride (HgCdTe) detectors contain mercury, alternative detectors using materials with lower environmental impact are being explored, such as those based on indium antimonide (InSb) and indium arsenide antimonide (InAsSb). These InSb- and InAsSb-based detectors, however, require liquid nitrogen cooling, as well as external wavelength and angular filters to reduce thermal noise from the surrounding environment.

In this context, Toshiba Corporation, in collaboration with NIMS of Japan, has succeeded in developing the world's first mid-infrared surface-illuminated quantum cascade detector(*). This detector does not require cooling and eliminates the need for external optical filters by using a photonic crystal that selectively guides only light of specific wavelengths and incident angles into the detection layer. By combining this detector with a surface-emitting quantum cascade laser currently under development, we aim to achieve highly sensitive gas sensing.

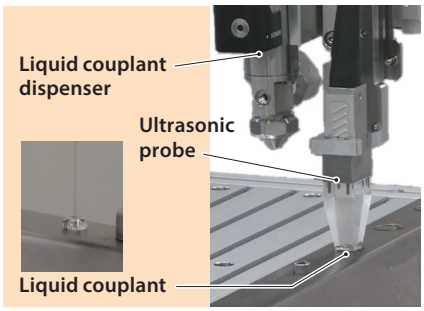
Part of this work was funded by the Acquisition, Technology & Logistics Agency (ATLA) of the Ministry of Defense of Japan under the Security Technology Research Promotion Program, Grant Number JPJ004596.

(*) As of November 2025 (according to Toshiba Corporation research)

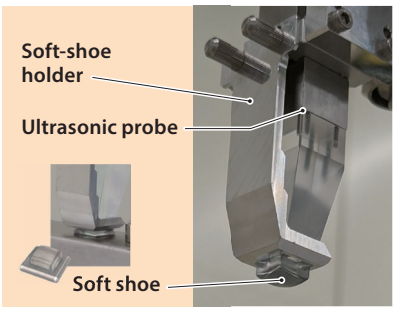
1.30 Automated Spot-Weld Inspection Robot Eliminating Need for Liquid Couplant



Configuration of automatic spot-weld inspection robot



Inspection head using conventional liquid couplant



New inspection head with soft shoe attached to probe tip

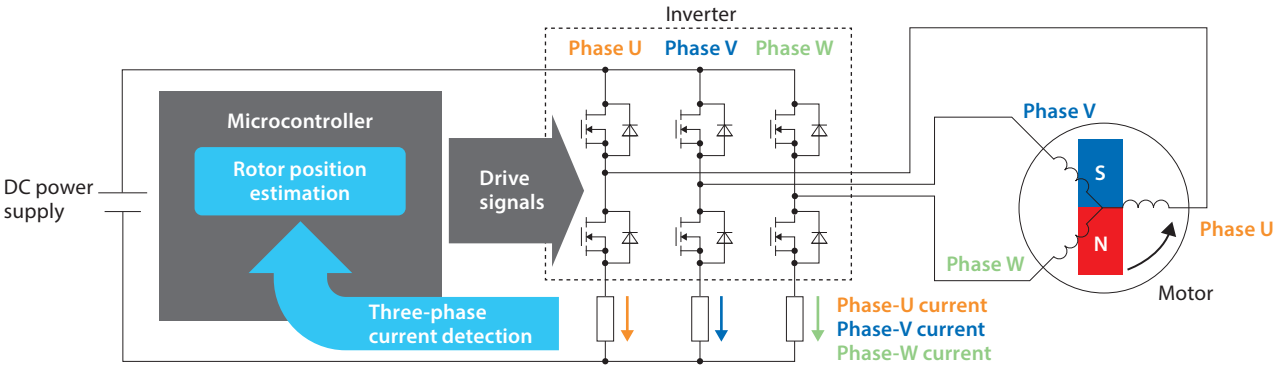
In manufacturing plants, including those producing automobiles and other products where components are joined by spot welding, there is increasing demand for automated spot-weld inspection robots to enhance inspection efficiency and ensure consistent quality.

Toshiba Corporation has been developing an automated spot-weld inspection robot that integrates ultrasonic nondestructive testing with robot control based on a tilt estimation engine, which optimizes the angle of the ultrasonic probe during inspection. In conventional ultrasonic nondestructive testing, a liquid couplant must be applied to enable ultrasonic waves to propagate from the probe into the interior of the object under inspection, after which it must be removed.

To eliminate these steps and thereby reduce inspection time, we have developed a solid, gel-like contact medium called a “soft shoe,” which is attached to the tip of the probe as an alternative to a liquid couplant, and have conducted repeated performance evaluations on automotive components. Improvements in the shape of the soft shoe have enhanced its adhesion to the inspection target, thereby reducing measurement variability and improving the reproducibility of pass/fail determinations.

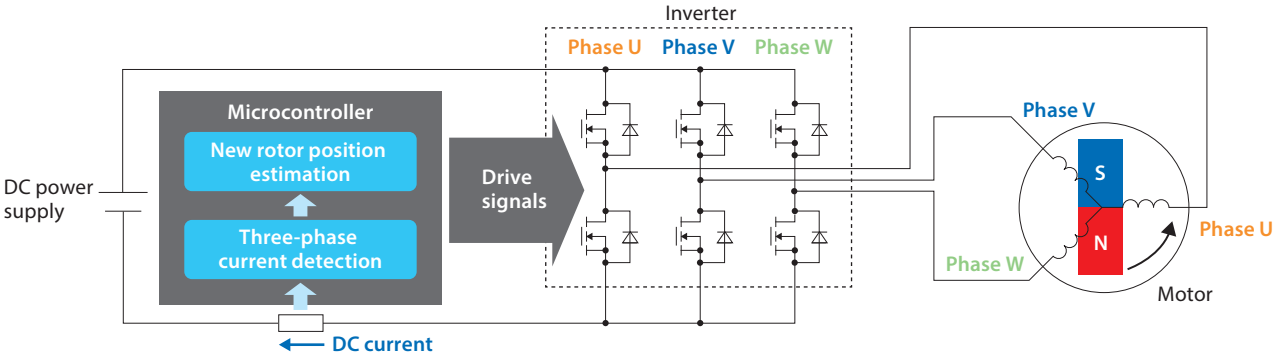
Going forward, we will continue to pursue further practical enhancements, such as refining the mechanism to facilitate attachment of the soft shoe, and promote its application to production lines.

1.31 Rotor Position Estimation in Low-Speed Range for Permanent Magnet Motors with Single Current Detector



To estimate rotor position in low-speed range, three current detectors are required to detect currents flowing through three phases.

Conventional motor drive system with three current detectors



To estimate rotor position in low-speed range, only one current detector is required to detect currents flowing through three phases.

New motor drive system with single current detector

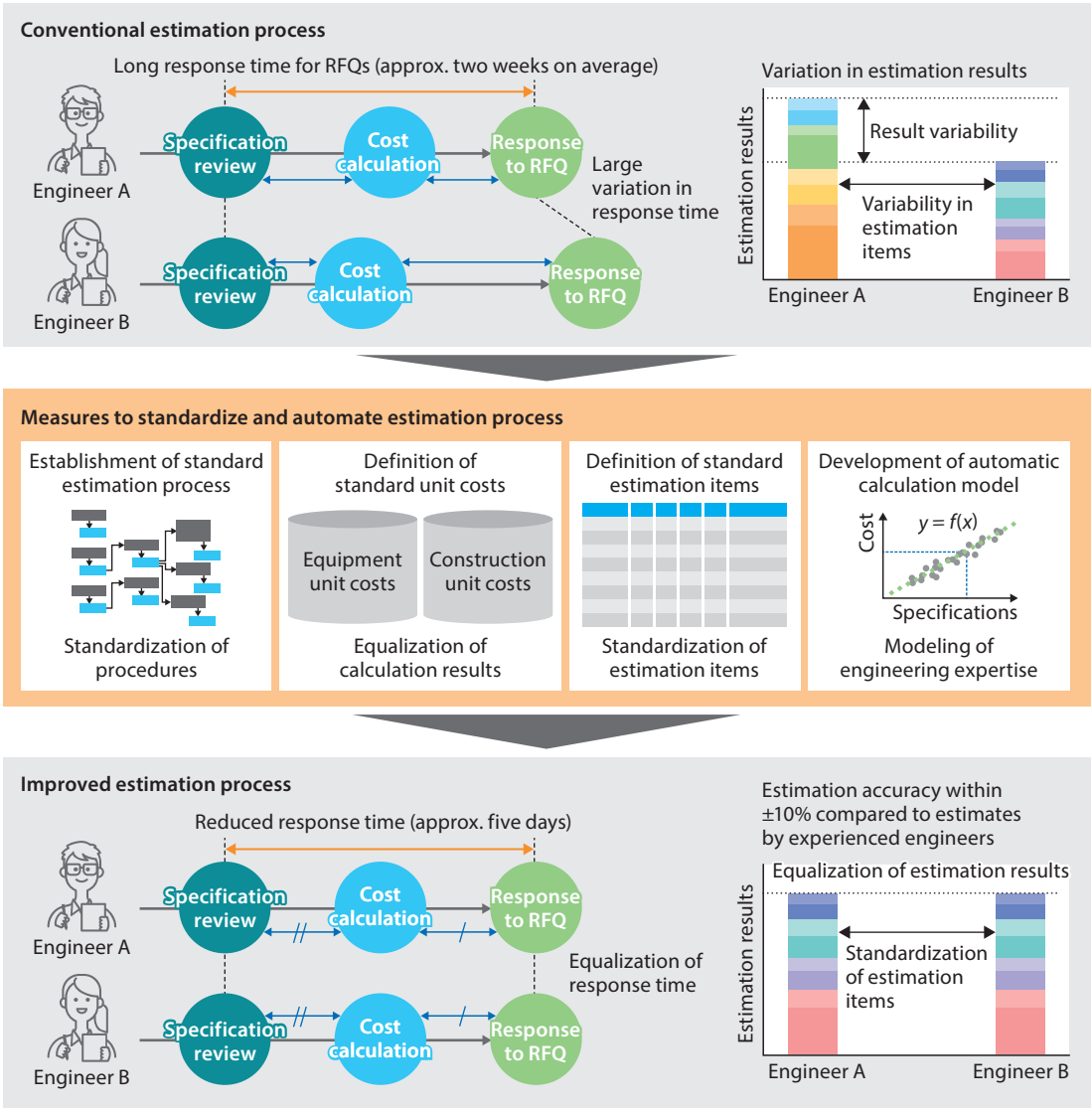
To operate a permanent magnet motor without a rotor position sensor, it is necessary to accurately estimate the rotor position using alternative methods. Although techniques for rotor position detection in the high-speed range have already been established, those for the low-speed range still require improvement.

Previously, Toshiba Corporation estimated the rotor position in the low-speed range using current detectors installed in each phase of a three-phase inverter. However, reducing cost was a critical issue due to the use of three current detectors.

To address this issue, we have developed a method for obtaining the currents of all three phases using only a single current detector installed between the DC power supply and the inverter. The DC current flowing through the detector is measured in synchronization with the inverter switching signals. In addition, we have developed a new rotor position estimation method compatible with this approach. Together, these methods reduce the number of current detectors to one, thereby lowering system cost.

In the future, we will promote the application of these methods to a wide range of products, including motor drive systems for consumer and automotive applications.

1.32 Transformation of Quotation Processes for Photovoltaic Power Generation and Battery Energy Storage Systems



Standardization and automation solutions for improving renewable energy project estimation accuracy

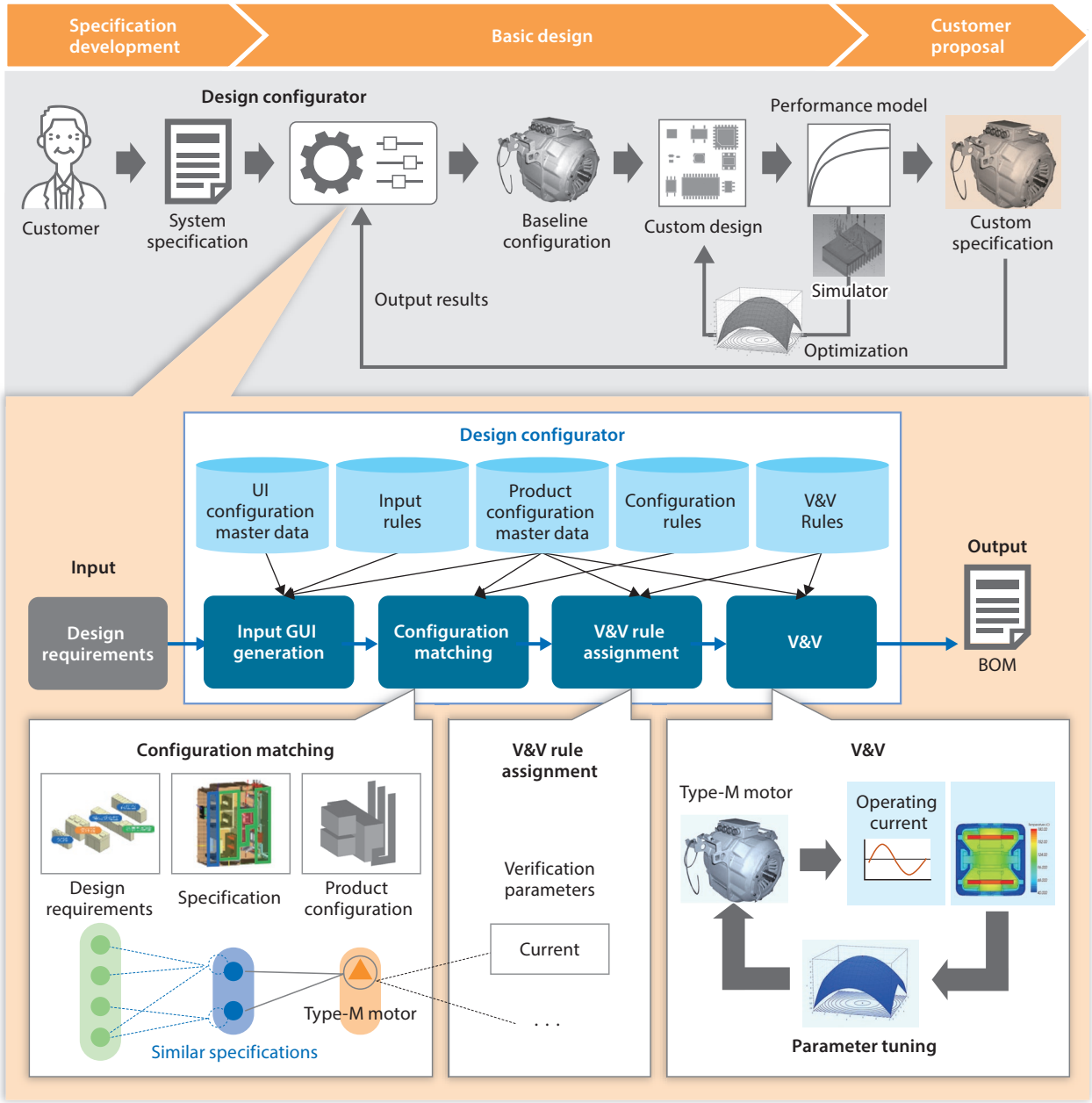
With the expansion of the renewable energy (RE) market, demand for photovoltaic (PV) power generation systems has been increasing rapidly. In addition, changes in RE-related regulations have necessitated more accurate assessments of project profitability, thereby requiring highly accurate cost estimation. However, the estimation process has traditionally relied heavily on individual engineers, posing challenges for improving estimation accuracy and reducing the time required to respond to requests for quotations (RFQs).

To address these challenges, Toshiba Corporation organized project-specific specifications and estimation items into patterns based on system configuration, scale, and construction scope, focusing on the estimation process for PV and battery energy storage systems, and established a standardized estimation process by extracting common elements. As a result, specifications,

estimation items, calculation procedures, and unit costs required for estimation were standardized, thereby reducing the variability and improving the efficiency of cost estimation.

Furthermore, based on the standardized specifications, we developed a preliminary cost estimation tool that automatically calculates costs using an estimation model designed to derive costs from key parameters such as power generation capacity and environmental conditions. This tool reduced the time required to respond to RFQs by approximately 50% and enabled rapid adaptation to market changes. Its accuracy was confirmed to be within ±10% of estimates made by experienced engineers, demonstrating its suitability for practical use. The cost estimation tool has been implemented in practical applications.

1.33 Design Configurator for Automated Specification Adjustment and Verification and Validation Using MBD approach



UI: user interface GUI: graphical user interface BOM: bill of materials

Engineer-to-order manufacturing process utilizing design configurator

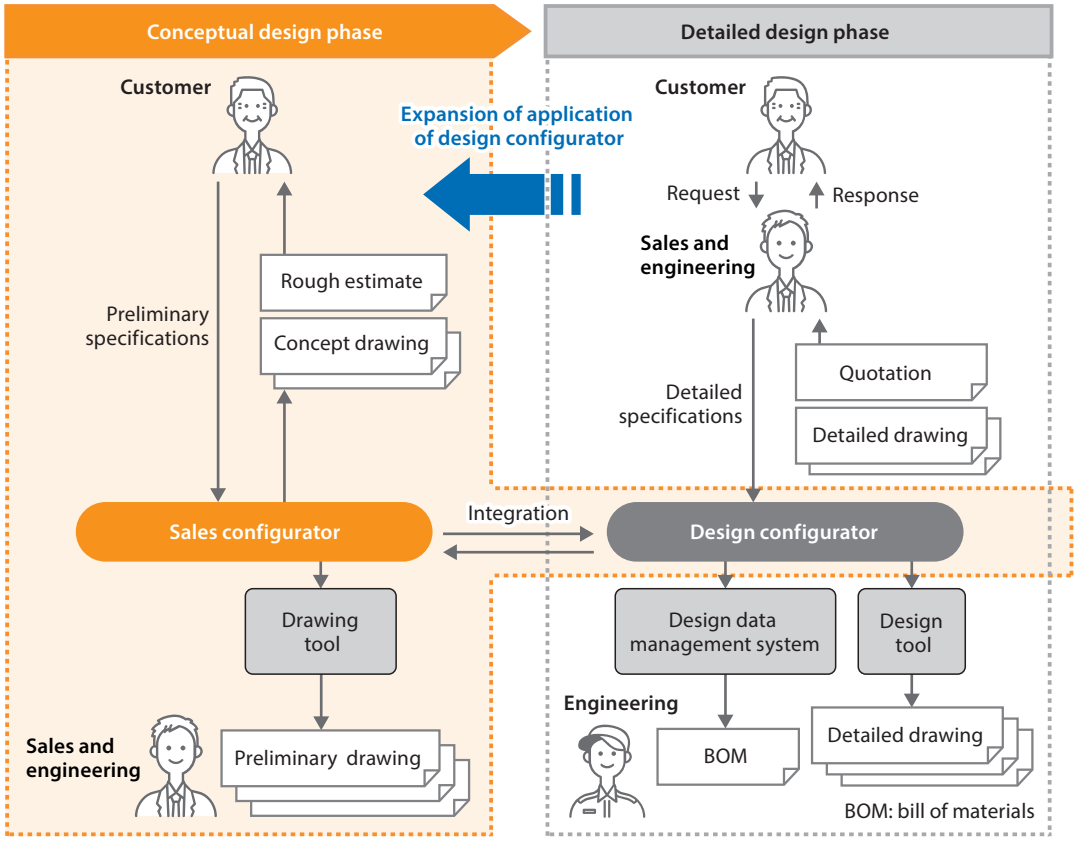
In engineer-to-order (ETO) manufacturing, customized design is essential to accommodate customer-specific requirements. Conventionally, designers have relied on manual, iterative processes— reviewing, adjusting, and validating specifications while referring to past design cases. However, this approach is highly dependent on individual expertise, often leading to frequent design changes and rework, and ultimately results in prolonged design lead times.

To address these issues, Toshiba Corporation has developed a design configurator based on an MBD approach to automate product configuration and validation processes in ETO environments. This configurator identifies optimal design configurations from existing product assets based on custom specifications. By leveraging performance models and external simulation interfaces, it automatically derives design parameters and facilitates rigorous verification and validation (V&V), thereby significantly streamlining the initial design phase.

The pilot trial conducted on infrastructure system products confirmed that the design configurator effectively reduces design rework, indicating that it can shorten overall design lead times.

We plan to apply the design configurator to actual product design workflows to further enhance operational efficiency.

1.34 Sales Configurator for Automating Drawing Generation and Preliminary Cost Estimation in Conceptual Design



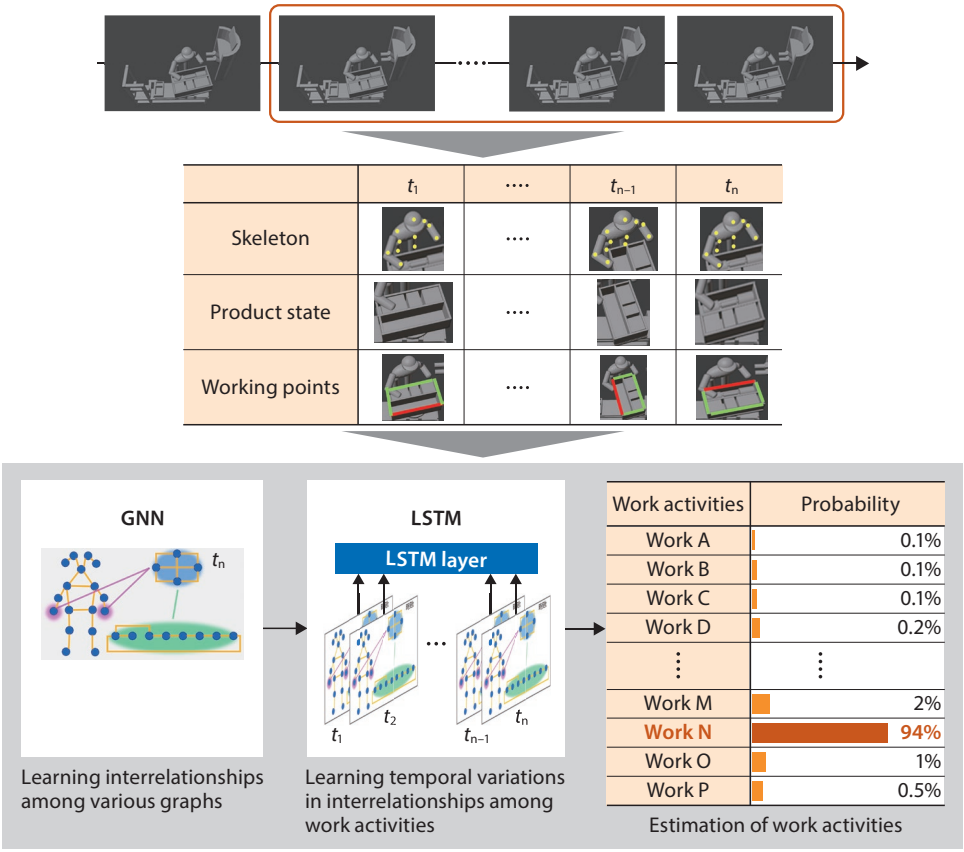
Engineer-to-order product development process using sales and design configurators

For engineer-to-order products, the amount of specification information available from customers often differs between the conceptual design phase in the early stages of planning and the detailed design phase in later stages. Moreover, during conceptual design, multiple alternatives must frequently be evaluated in parallel, and specification changes are common. Consequently, there is a need to rapidly provide preliminary cost estimates and drawings for proposed options based on limited specification information.

To address this issue, Toshiba Corporation has developed a sales configurator applicable in the conceptual design phase. This tool operates in conjunction with a design configurator used by internal engineering departments. Based on simplified specifications provided by customers, it derives product configuration information and rapidly generates preliminary cost estimates and drawings required for proposals. Furthermore, to accommodate diverse customer requirements in the detailed design phase, the sales configurator ensures accurate transfer of specification information to the design configurator, thereby enabling a seamless transition from conceptual to detailed design.

We have already applied this sales configurator to products for infrastructure facilities and plan to further expand its functionality in response to customer needs.

1.35 Method for Accurate Task Recognition Based on Temporal Changes in Workers' Skeletal Positions and Product States



Overview of work estimation method combining GNNs and LSTM networks

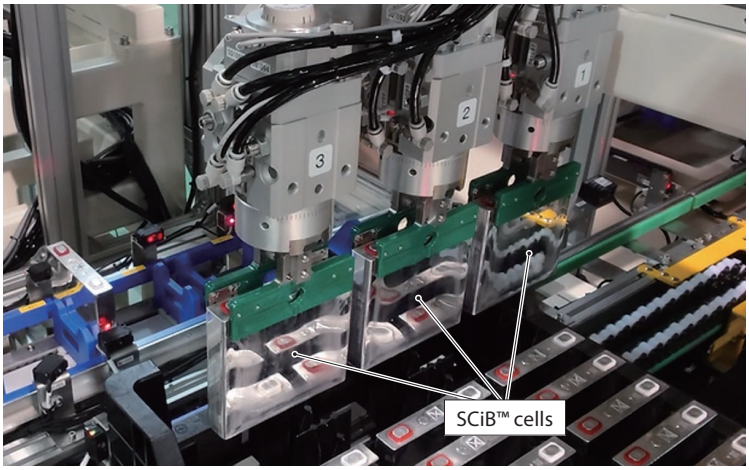
To reduce labor costs associated with work progress management on the manufacturing floor, Toshiba Corporation has developed a technology that automatically tracks work progress using video analysis. Accurate estimation of work activities is essential for enabling such automated tracking. However, when a single worker performs complex and diverse assembly tasks over extended periods, achieving high-precision estimation becomes difficult due to tasks being performed in similar postures and positions.

To address this challenge, Toshiba Corporation proposes a novel method that integrates multiple types of temporal work-related data, such as workers' skeletal positions, product states, and working points. The estimation model combines a graph neural network (GNN), which learns both the intrinsic features of work information and their relationships, with a long short-term memory (LSTM) network, which captures temporal variations in these features. This combination enables the model to capture detailed characteristics of work activities. Experimental evaluation using actual work data demonstrated that the proposed method achieves an estimation accuracy exceeding 90%.

We plan to deploy this method across our factories both in Japan and overseas to enable the automation of work progress management.

1.36 Development and Implementation of Automated Visual Inspection System for SCiB™ Cell Manufacturing

SCiB™ lithium-ion rechargeable battery cells



Automated transfer mechanism for simultaneous handling of multiple SCiB™ cells

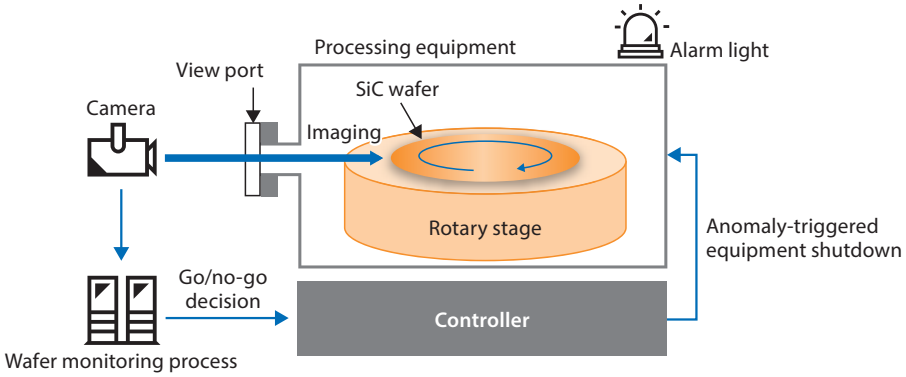
Toshiba Corporation has developed and implemented an automated visual inspection system for the manufacturing of SCiB™ lithium-ion rechargeable battery cells to enhance quality control and reduce operator workload.

Previously, operators performed 100% visual inspection and manual transportation of the cells, which posed challenges in maintaining consistent inspection quality, preventing short-circuit incidents, and ensuring safe handling of heavy cells.

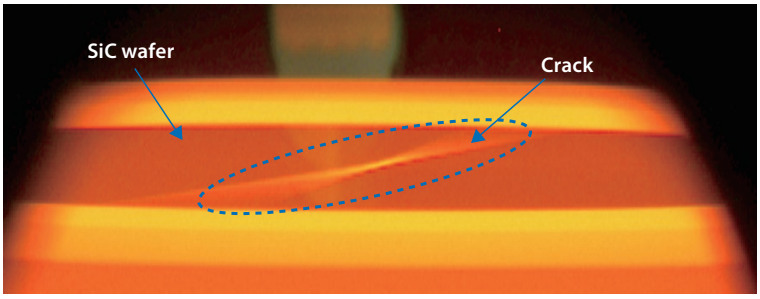
The newly introduced automated visual inspection system combines a line sensor with stripe-pattern illumination, enabling high-precision imaging and inspection of SCiB™ cells. This configuration allows stable detection of minute dents and contaminants, thereby improving inspection quality. In addition, we have developed an automated mechanism capable of simultaneously gripping and transporting multiple SCiB™ cells, achieving the target takt time while eliminating manual handling by operators. This helps prevent short-circuit incidents and ensures operational safety.

Going forward, we plan to deploy this visual inspection system in new manufacturing lines and leverage inspection data to further improve manufacturing processes.

1.37 Wafer Anomaly Detection Technology for SiC Process Equipment



Wafer anomaly detection system schematic



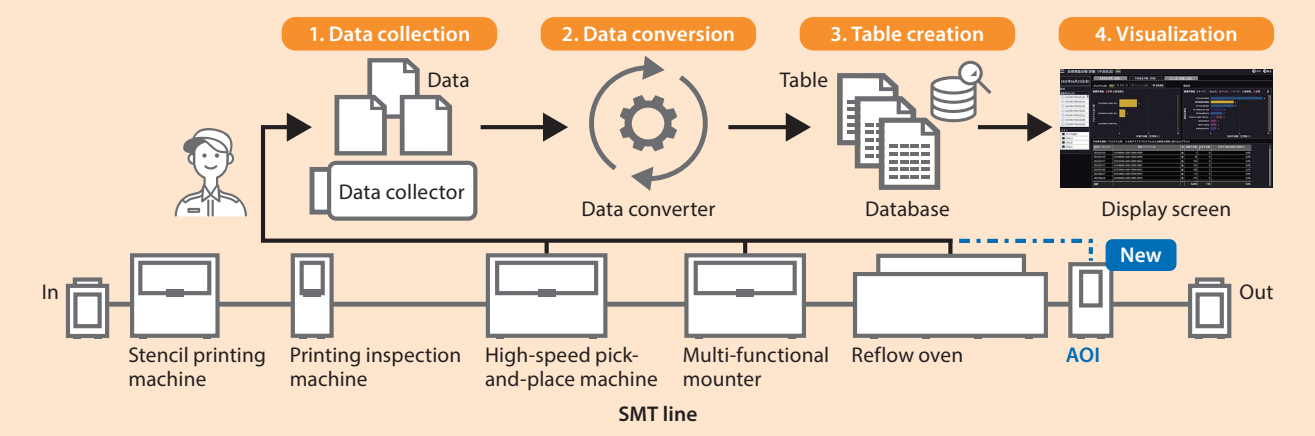
Example of detected wafer crack

As part of efforts to achieve carbon neutrality, silicon carbide (SiC) semiconductor devices, which offer low power consumption, have attracted significant attention and are increasingly adopted, particularly in applications such as electric vehicles. To improve the utilization rate of processing equipment for SiC wafers, which are essential for the development and manufacturing of SiC devices, Toshiba Corporation has developed a real-time wafer anomaly detection technology based on camera images.

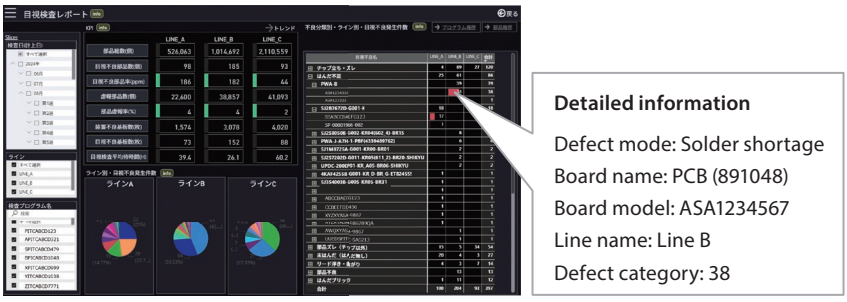
In the SiC device manufacturing process, wafers may crack due to internal defects. If such cracking progresses and causes wafer fragments to scatter inside the equipment, a significant amount of time is required to restore the equipment, making the development of countermeasures a critical challenge.

The proposed wafer anomaly detection technology continuously monitors SiC wafers during processing using an external camera and detects wafer cracking in real time through image analysis. High-accuracy crack detection is achieved through frame-by-frame comparison of video images. Experimental verification confirmed that cracking can be detected at an early stage, enabling the processing equipment to be safely shut down, and demonstrated that the proposed technology is effective in improving equipment utilization.

1.38 Enhancement of Quality Visualization Functions of Meister Apps to Support Improvement of Electronic Circuit Board Manufacturing Processes



Updated version of Meister Apps Process Improvement Assist Package for SMT Lines configuration



Screen displaying manufacturing knowledge in updated version of Meister Apps Process Improvement Assist Package for SMT Lines

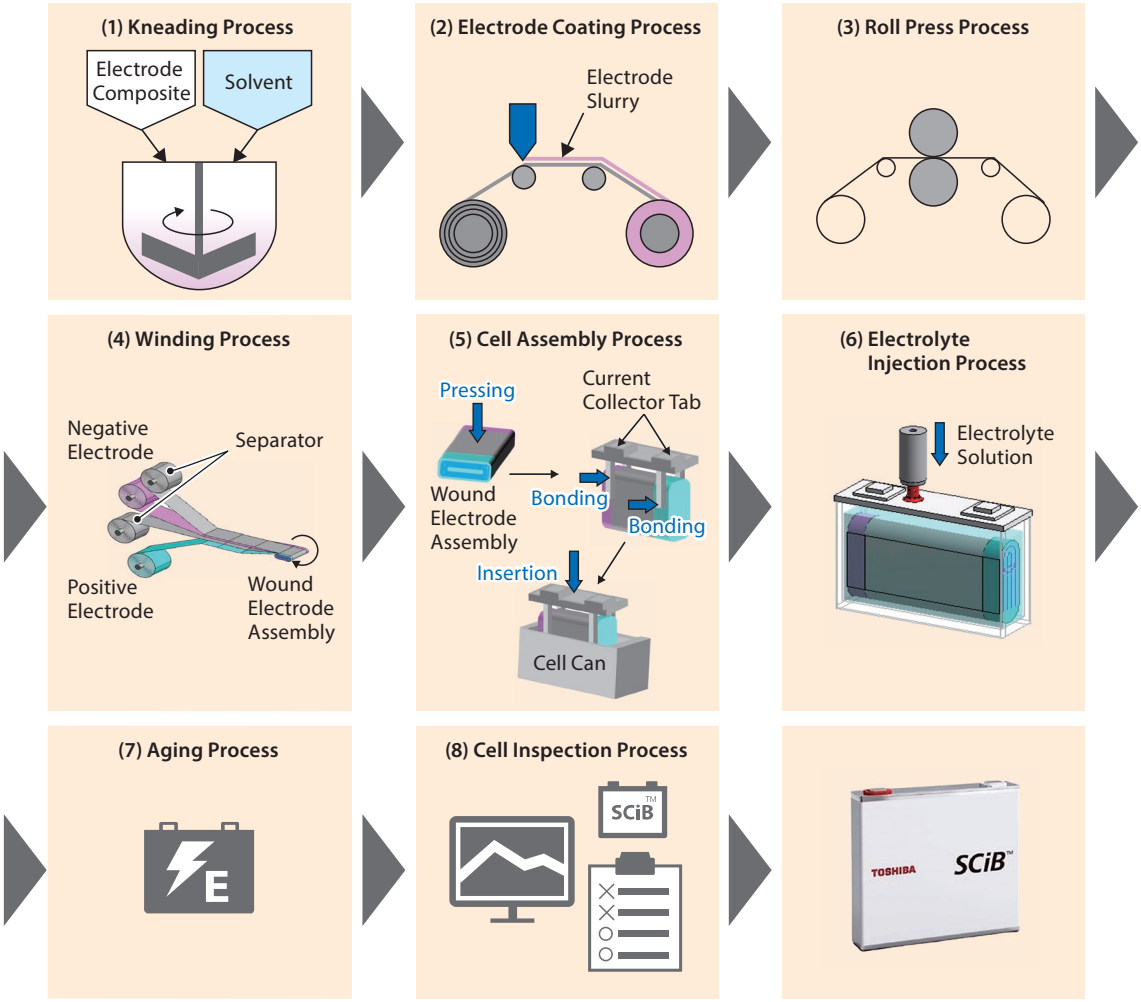
Targeting surface-mount technology (SMT) lines, in which electronic components are mounted on printed circuit boards, Toshiba Corporation has commercialized the Meister Apps Process Improvement Assist Package for SMT Lines, an IoT-based system designed to realize smart manufacturing through the visualization of pick-and-place (PnP) machines, which are central to the SMT process.

This is an updated version to address market demands for more advanced production and quality management. By leveraging data from automated optical inspection (AOI) systems and integrating inspection results with production status data, the updated system enables the detection of defect trends and the rapid implementation of countermeasures, thereby enhancing both the speed and accuracy of quality improvement efforts.

Prior to this update, a prototype was evaluated at internal production facilities to analyze the relationships between PnP machine errors and AOI-detected defects. As a result, the causal relationships underlying anomalies were clarified, yielding new benefits, such as defect reduction through the review and optimization of PnP machine operating conditions.

We are currently developing a function for recommending improvement actions based on accumulated data, with the aim of achieving further functional enhancements.

1.39 Pursuit of Zero Winding Misalignment in Battery Manufacturing for Enhanced Quality and Throughput



SCiB™ manufacturing process

To reduce the manufacturing costs of SCiB™ lithium-ion rechargeable batteries, Toshiba Corporation conducted a comprehensive review of the entire manufacturing process, implemented measures to improve material yield and increase production capacity, and quantitatively verified their effectiveness.

In battery manufacturing, the winding process—where the positive electrode, negative electrode, and separator are precisely stacked and wound into a roll to achieve the required battery performance—has been a major source of defects, notably winding misalignment, in which the relative positions of the electrodes and separator deviate during winding. To address this issue, we combined a technology for the handling of web (long, flexible materials) with optimization of the shape and material of guide rollers, taking into account the specific characteristics of electrode materials. In addition, the friction force between the guide rollers and the electrodes was controlled through enhanced tension control of the equipment. As a result, stable and high-

speed material transport was achieved, thereby significantly increasing production capacity. These improvements also reduced the defect rate in the winding process by approximately 3%. By improving three major processes affecting material yield, including the winding process, annual material losses were reduced by approximately 600 million yen.

Going forward, we will continue to improve manufacturing processes by leveraging data analysis, with the aim of sustainably enhancing business value in terms of both quality and cost competitiveness.