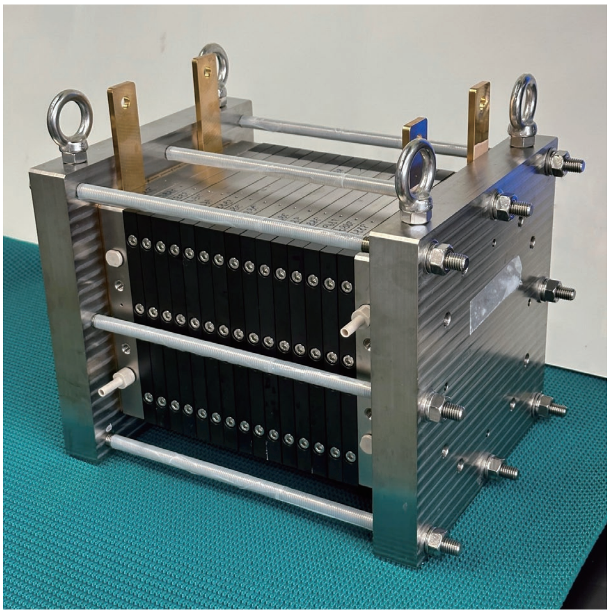
1. Research and Development

1.1 Electrolysis System for Converting CO_2 into Valuable Substances



Cell stack for CO_2 electrolysis consisting of 10 cells with electrode area of 100 cm^2

CO_2 electrolysis system used in demonstration

To achieve carbon neutrality by 2050, it is essential to accelerate social implementation of large carbon dioxide (CO_2) electrolysis systems for converting CO_2 into valuable chemicals. Because CO_2 conversion throughput is crucial for social implementation, Toshiba Corporation has experimented with our proprietary CO_2 electrolysis system to increase its size and robustness.

We fabricated a 10-cell CO_2 electrolysis stack with 100 cm^2 electrodes for a bench-scale CO_2 electrolysis system and evaluated continuous operation. This system incorporates a high-performance CO_2 electroreduction catalyst and electrodes to increase CO_2 conversion throughput to convert a maximum of one ton of CO_2 into carbon monoxide (CO) per year.

We demonstrated the bench-scale CO_2 electrolysis system under simulated real-world conditions to clarify its capability to convert CO_2 gas with trace impurities recovered from coal-fired power plants and determine the tolerance of the CO_2 electroreduction catalyst to such impurities. The demonstration indicates that CO_2 gas with trace impurities has no significant impact on catalytic performance compared to using pure CO_2 gas, proving the catalyst's tolerance to impurities.

In addition, we evaluated the impact of power fluctuations on the cell, as this is important when operating the CO_2 electrolysis system using renewable energy. The simulation verified that our CO_2 electrolysis cell is capable of tracking periodic power fluctuations of renewable energy sources.

The next step is to further increase the system size and CO_2 conversion speed to contribute to achieving a carbon-neutral society.

Part of this research was conducted under a project commissioned by the Ministry of the Environment of Japan entitled “Project to Promote the Creation of Circular Carbon Society Model Through CO_2 Recycling (Verification of a Community-Compatible CO_2 Recycling Model Based on Artificial Photosynthesis Technologies at Large CO_2-Emitting Facilities).”

1.2 Dual-Sided Multi-Gate IGBT Technology to Improve Efficiency and Reduce Power Loss of Power Electronics Systems

To achieve carbon neutrality, it is crucial to reduce the power loss of insulated-gate bipolar transistors (IGBTs), which drive electric motors for wind farms, electric vehicles (EVs), and other applications. IGBTs offer both high breakdown voltage and low conduction loss by accumulating electron-hole pairs at high density. However, accumulated electron-hole pairs cause significant power loss during on-to-off switching (turn-off) when expelled from the IGBT.

The trade-off between conduction and turn-off losses depends on the density of the electron-hole pairs. This has traditionally been improved by thinning the IGBT chip to enhance performance, however, this approach has reached its limit as it shows signs of saturation.

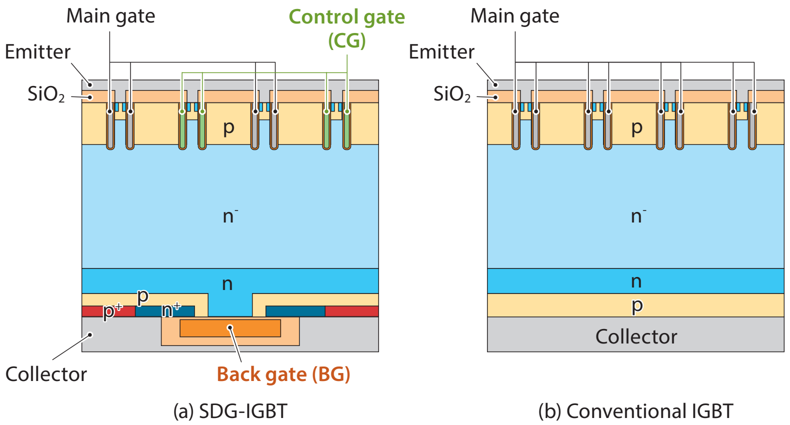
To solve this issue, Toshiba Corporation has developed a breakthrough device known as a single-back and double-front gate-controlled IGBT (SDG-IGBT), adding gates to both the front and back of the conventional IGBT. The SDG-IGBT now has three independently controllable gates. It maintains on-state electron-hole pairs at high density to achieve low conduction loss while pre-activating only the added gates in the off-state to reduce the density of electron-hole pairs and thereby achieve low turn-off loss. The SDG-IGBT therefore provides both low conduction and turn-off loss when added gates are driven immediately before turn-off to reduce electron-hole pair density.

Furthermore, the SDG-IGBT provides a wider area from which electron-hole pairs are expelled than conventional multi-gate IGBTs with only a main gate. This results in SDG-IGBT turn-off loss up to 34% lower than that of conventional standard IGBTs and 12 to 22% lower than that of single-sided multi-gate IGBTs.

The advancement and proliferation of SDG-IGBT technology is expected to help reduce power electronics system power consumption and contribute to the goal of carbon neutrality.

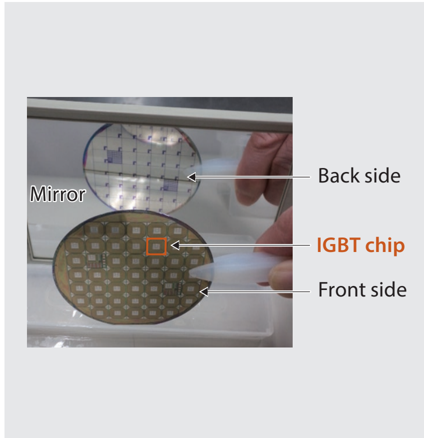
This achievement is the result of collaborative research between the Hiramoto Laboratory at the University of Tokyo and Toshiba Device & Storage Corporation.

1. Research and Development

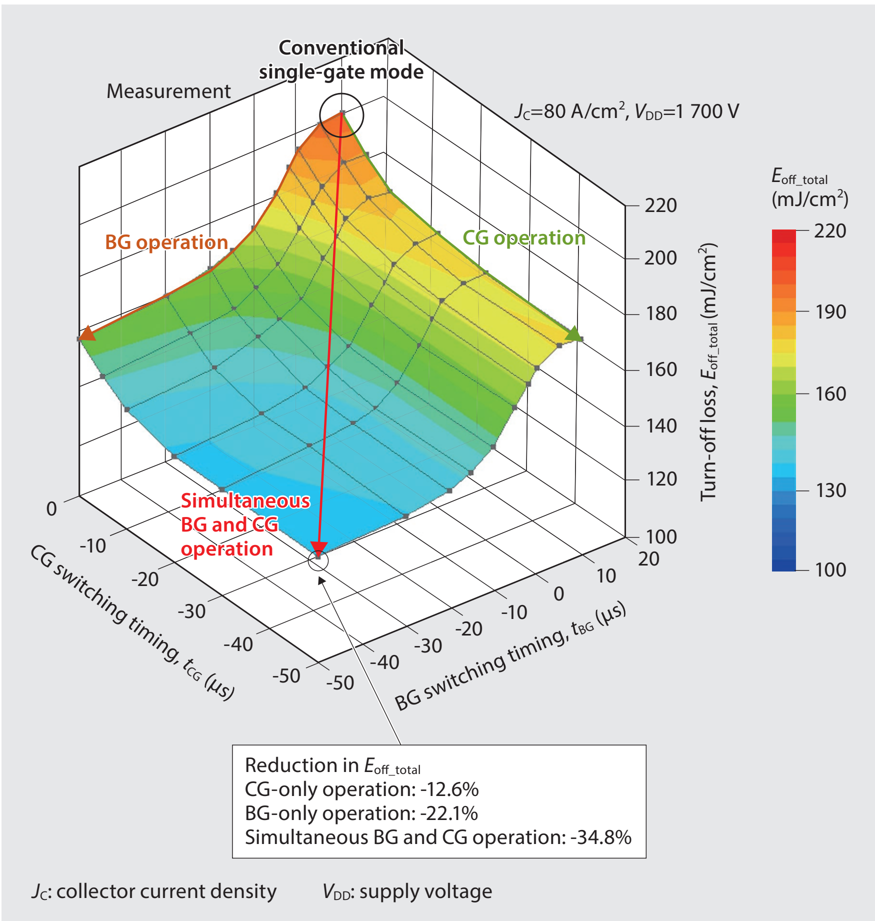


p: p-type Si p^+: heavily doped p-type Si   n: n-type Si
n^+: heavily doped n-type Si n^-: lightly doped n-type Si

Comparison of cross-sectional views of SDG-IGBT and conventional IGBT

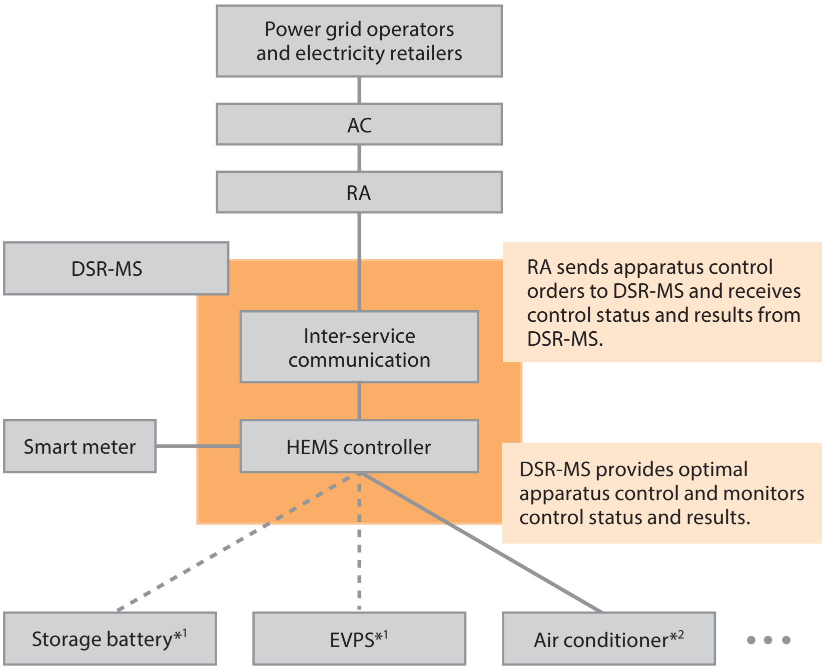


Prototype SDG-IGBT



Comparison of conventional IGBT and SDG-IGBT switching loss

1.3 Release of Guidelines for Using Consumer Energy Resources for VPP Services (Second Edition)



AC: aggregation coordinator
HEMS: home energy management system
*1: Equipment that can be controlled with DSR-MS by specifying power usage in kW or kWh
*2: Equipment that cannot be controlled with DSR-MS by specifying power usage in kW or kWh

Application of DSR-MS to DR control system

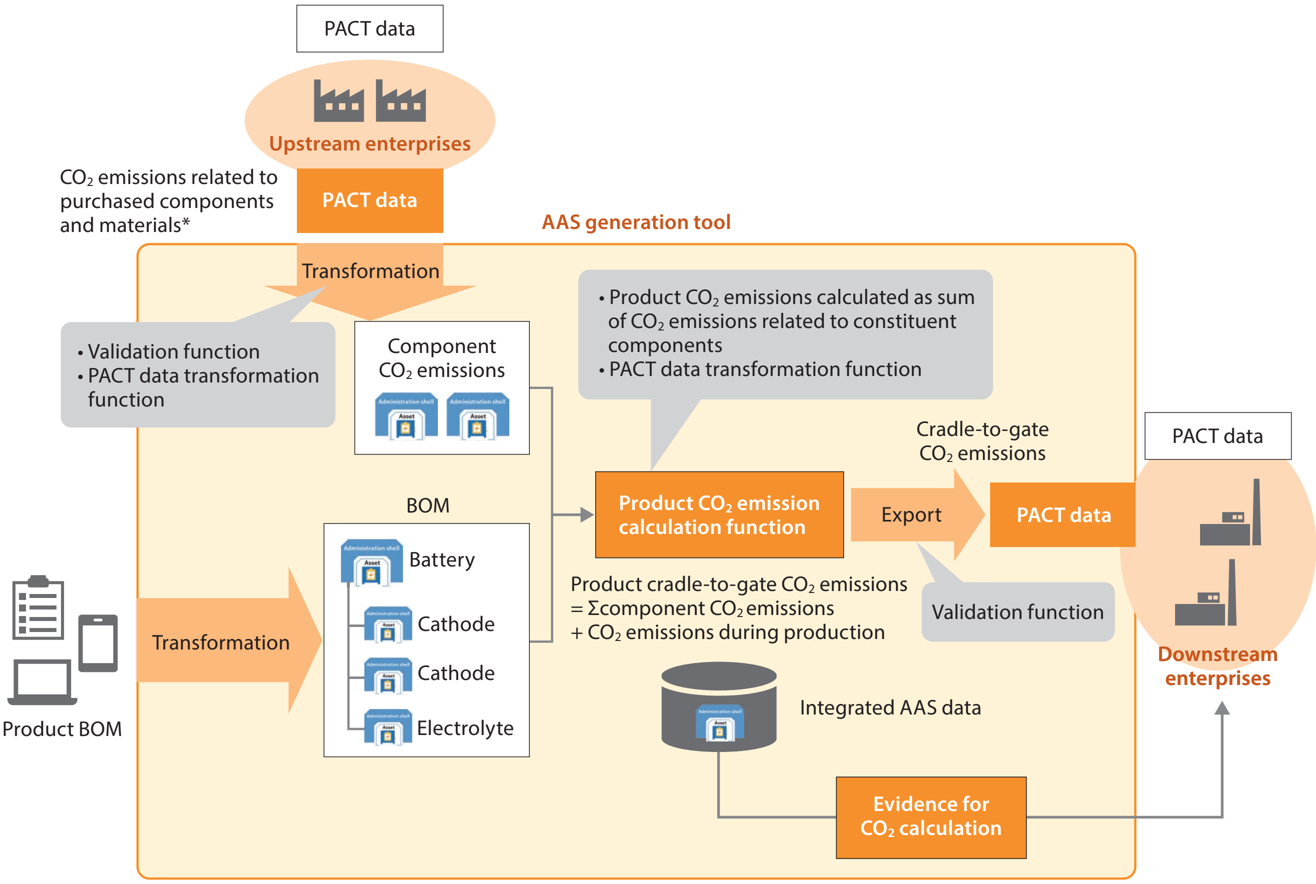
Led by Toshiba Corporation, the VPP Subcommittee (17-member ECHONET Consortium) under the Japan Electrical Manufacturers' Association (JEMA) IoT/Smart Energy Committee has released the second edition of the Guidelines for Using Consumers' Energy Resources for VPP Services.

This edition reflects the latest movement to achieve carbon neutrality, including various institutional programs and trends in the development of consumer resources. It also provides guidelines for utilizing consumer energy resources so that resource aggregators (RAs) which provide virtual power plant (VPP) services will be able to achieve more accurate demand-response (DR) control. In addition, the second edition defines the Demand Side Resources-Energy Management System (DSR-MS) to bundle consumer resources such as batteries and electric vehicle power stations (EVPS), contains a list of revised definitions of data between DSR-MS and RA, and discusses usage of the ECHONET Lite™ Web Application Programming Interface (API).

We will apply and continue reviewing the guidelines to deal with new issues such as group control, measurement of individual energy resources, and frequency control.

ECHONET Lite™ is a trademark of ECHONET Consortium.

1.4 Ecosystem for Product Carbon Footprint Data Applying Data Interoperability Technology



* Calculation and reporting of greenhouse gas (GHG) lifecycle emissions based on GHG Protocol

Overview of product carbon footprint exchange experiment using data interoperability technology

Toshiba Corporation is working to facilitate the exchange of carbon-footprint-of-product (CFP) data among different systems and stakeholders using the Asset Administration Shell (AAS) generation tool based on interoperability technology. As part of this initiative, we participated in a CFP data exchange proof of concept (PoC), and distribution organized by the Green x Digital Consortium of the Japan Electronics and Information Technology Industries Association (JEITA).

For this PoC, we developed functions to integrate AAS-compatible product data with CO_2 emission data based on the Partnership for Carbon Transparency (PACT) Pathfinder Framework from the World Business Council for Sustainable Development (WBCSD). This makes it possible to calculate a product's CO_2 emissions automatically based on a bill of materials (BOM) in the AAS and upstream CO_2 emission data. Cradle-to-gate CO_2 emissions for a product can therefore be obtained by adding it to CO_2 emissions during production and then transferred to downstream product users.

To achieve this, we developed the following functions:

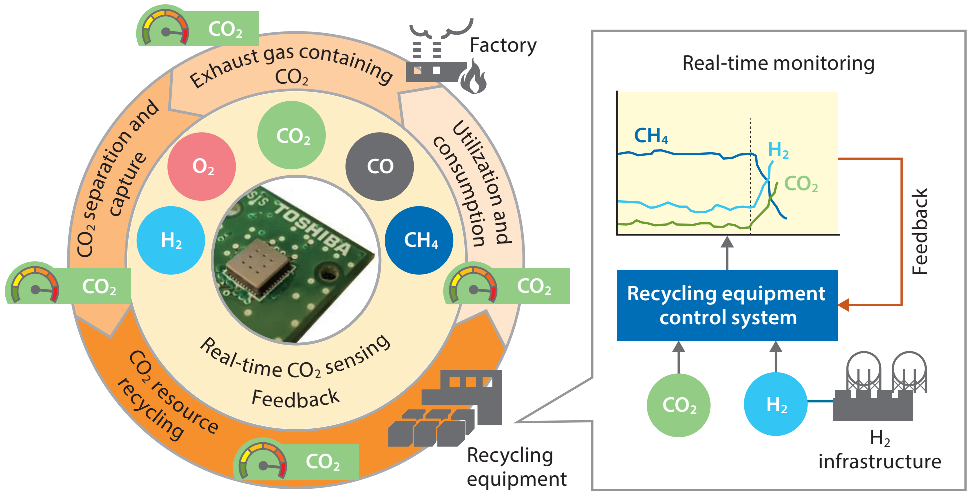
(1) a function for transformation between the PACT and AAS data models

(2) a function to validate consistency between the AAS data models and data, and between PACT data models and data

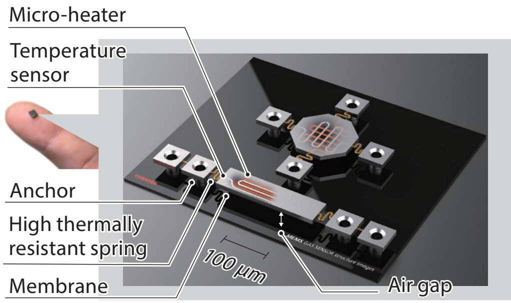
(3) a function to calculate a product's CO_2 emissions by aggregating CO_2 emissions from its components, product production, etc.

The PoC demonstrated the AAS generation tool's capability to seamlessly integrate product AAS data and PACT CO_2 emission data. It also ensures data correctness, accuracy, and consistency in accordance with AAS and PACT data model specifications. The above functions contributed to the success of the PoC and will be incorporated into our carbon-neutral enterprise products.

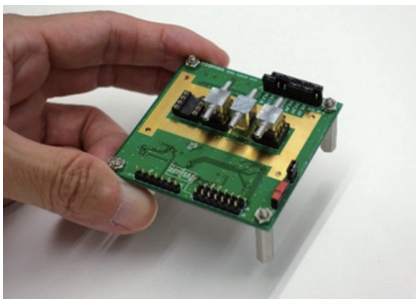
1.5 Mixed-Gas Sensing Technology Using Ultrasmall and High-Speed MEMS Gas Sensors



(a) Major gases generated during carbon recycling



(b) Device structure



(c) Prototype sensor module

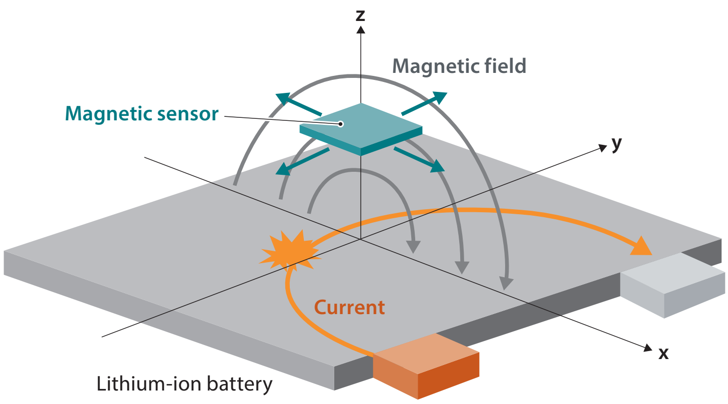
Structure of MEMS for thermal conductivity gas sensors and evaluation module

To achieve a carbon-neutral society, it is crucial to ensure the reliability of CFP data. However, greenhouse gas (GHG) emissions calculated using current methods and data estimated based on CO_2 equivalence are considered inaccurate and unreliable.

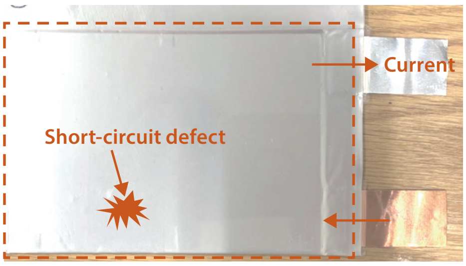
With this in mind, Toshiba Corporation has developed sensing technology to directly measure CO_2, hydrogen (H_2), and other gas concentrations in mixed gas. It uses an ultrasmall chip measuring only several square millimeters that integrates multiple microelectromechanical systems (MEMS) thermal conductivity gas sensors. Mixed-gas concentrations can be measured in real time in actual environmental conditions by processing data from each sensor using algorithms. Despite being 1/200th smaller than a conventional gas chromatograph, the new MEMS chip is more than 150 times faster.

The new technology helps to improve CFP data reliability and optimize carbon recycling technologies. It is also expected to have various applications in such fields as hydrogen infrastructure, indoor air quality monitoring, and respiratory healthcare.

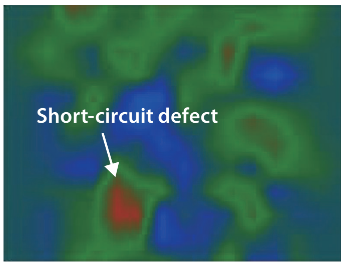
1.6 Compact High-Sensitivity Magnetic Sensor for Nondestructive Inspection of Lithium-Ion Battery Defects



Magnetic field microscope schematic



(a) Measured sample



(b) Magnetic field image

Magnetic field image of lithium-ion battery with short-circuit defect

High-sensitivity magnetic sensors have attracted much attention in applications such as non-destructive inspection of lithium-ion batteries and semiconductor chips.

Toshiba Corporation has developed a magnetic sensor that incorporates a unique anti-phase bridge circuit composed of giant magnetoresistive (GMR) elements using AC field modulation. As the anti-phase bridge circuit eliminates a modulation signal from its output signal, the new magnetic sensor achieves detectivity of 6 p T/√Hz (p: pico: 10^{-12}) at 10 Hz, which is 1/10^6 of the geomagnetic field. The size of the magnetic sensor was reduced to 2×8 mm by improving magnetic flux concentration efficiency.

We have applied the new magnetic sensor to a magnetic field microscope, enabling identification and visualization of short-circuit defects in a lithium-ion battery(*).

This work was supported by the Cabinet Office (CAO), Cross-ministerial Strategic Innovation Promotion Program (SIP), "Intelligent Processing Infrastructure of Cyber and Physical Systems" (funding agency: New Energy and Industrial Technology Development Organization (NEDO)).

(*) Measured by Integral Geometry Science, Ltd. using its own samples

1.7 Pilot Production of Large High-Capacity Rechargeable Batteries with Titanium-Niobium Oxide Anode Featuring Ultra-Quick Charging

Item	Specification
Appearance	
Nominal capacity	55 Ah
Operating voltage	2.95 to 1.50 V
Cell size	157×200×13 m (161×253×13 mm, including electrode tabs and sealing areas)
AC impedance (1 kHz)	Approx. 0.45 mΩ
Volumetric energy density	334 Wh/L (excluding electrode tabs and sealing areas)

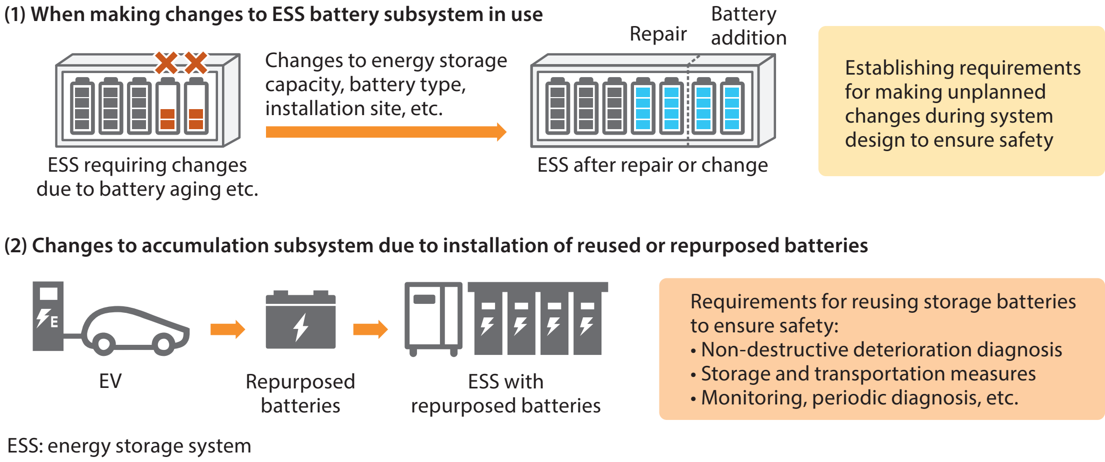
Specifications of large pouch cell for trial production

Electrification of commercial vehicles plays an important role in achieving a carbon-neutral society. Toshiba Corporation has developed a new battery with a titanium-niobium oxide (TNO: $TiNb_2O_7$) anode that has double the volumetric capacity of conventional graphite-based anodes, offers ultra-quick charging and discharging, and features excellent safety and a long lifetime.

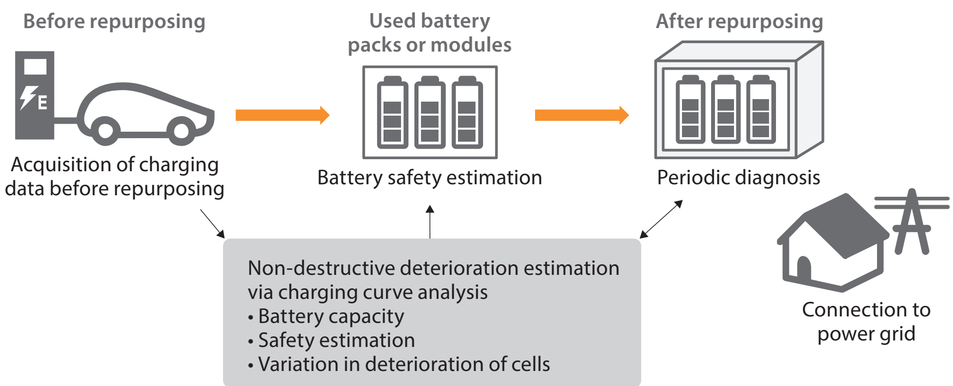
To bring it to the market, we have now developed a TNO anode using low-cost niobium. We have reduced the costs of TNO while minimizing the adverse effects of impurities and applied it to a prototype large battery cell with a nominal capacity of 55 Ah. We have also confirmed that the prototype battery cell delivers an energy density of 334 Wh/L, which is equivalent to that of lithium-iron phosphate batteries. Because of its high volumetric energy density and ultra-quick charging capabilities, the new battery cell can be charged to 80% in 10 minutes and maintain more than 95% capacity after 4 000 quick charging and discharging cycles, offering a long lifetime and excellent safety.

To help achieve carbon neutrality, we will promote the new battery for heavy-duty applications that have proved difficult to electrify with conventional lithium-ion batteries, such as large commercial vehicles and heavy machinery.

1.8 Charging Curve Analysis for Non-Destructive Safety Evaluation Described in Supplement to IEC Standard for Storage Battery System Safety



Safety requirements for stationary energy storage systems based on IEC 62933-5-3



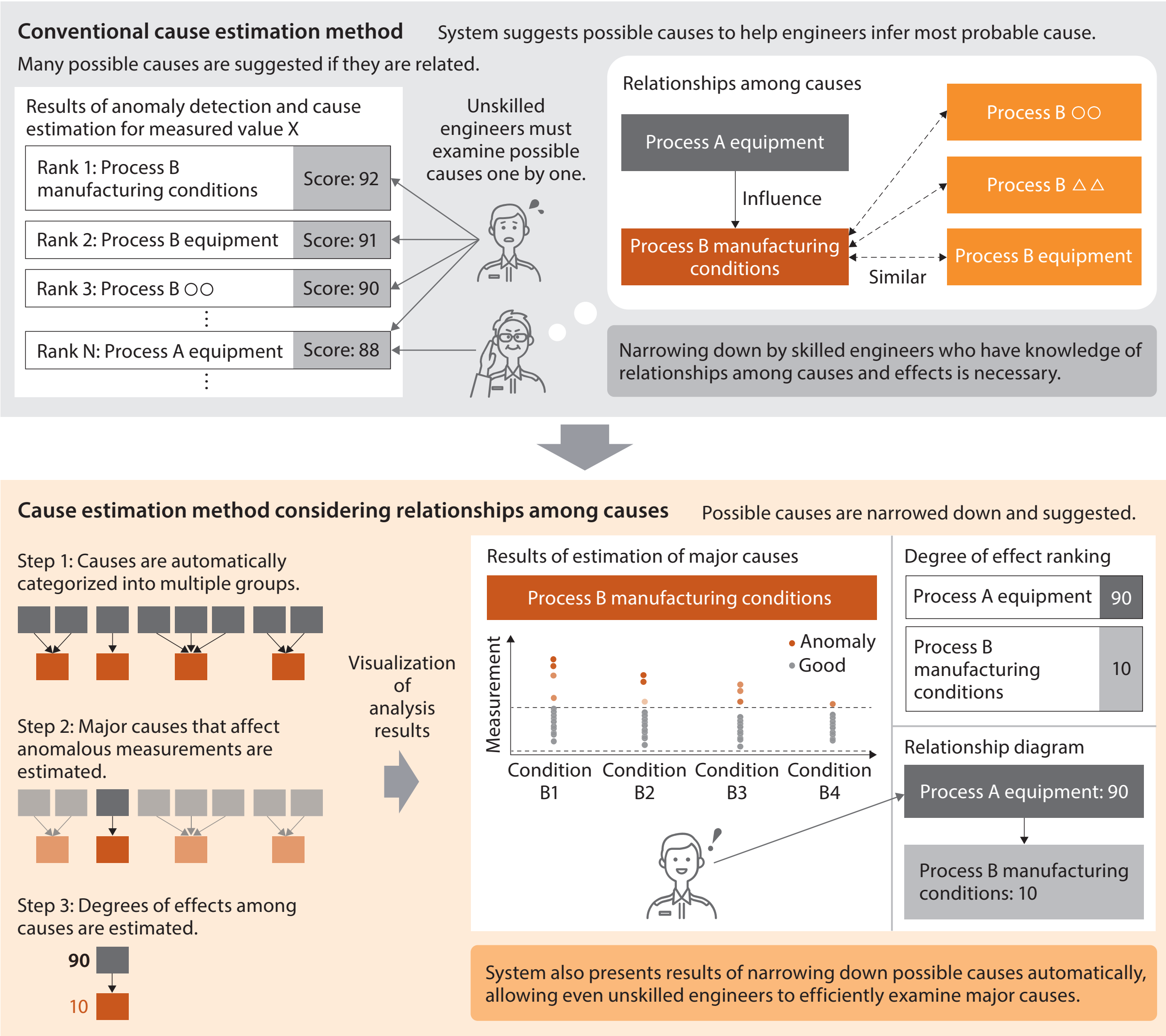
Non-destructive estimation of battery repurposing safety using charging curve analysis

The lithium-ion battery market is growing rapidly with the proliferation of EVs and renewable energy. However, such batteries pose safety concerns over fires, explosions and other hazards due to deterioration with age. With this in mind, Toshiba Corporation has identified that excessive deterioration of battery electrode materials can lead to fires, developing a non-destructive charging curve analysis method to estimate deterioration.

We also collaborated with the National Institute of Technology and Evaluation (NITE) and the Japan Electrical Safety and Environment Technology Laboratories (JET) to establish safety evaluation standards for storage batteries currently in use. Joint efforts resulted in including the charging curve analysis method in the International Electrotechnical Commission (IEC) 62933-5-3 standard proposed by the IEC TC120 National Committee, which was officially published in October 2023. This method allows non-destructive safety evaluation for repurposing storage batteries.

Furthermore, this standard is being utilized to certify used battery components under the JET Reused Battery Certification program. We will collaborate with our customers to enhance storage battery system safety and promote repurposing in-vehicle lithium-ion batteries using the charging curve analysis method.

1.9 System Enabling Unskilled Engineers to Identify Causes of Anomalies in SCiB™ Rechargeable Lithium-Ion Battery Cell Manufacturing Processes Through Data Analysis



Overview of cause estimation method considering relationships among multiple causes

At Kashiwazaki Factory, Toshiba Corporation has been working to improve SCiB™ rechargeable lithium-ion battery cell productivity using a system developed in-house for analyzing the causes of abnormal processes. The system helps engineers to monitor for anomalous values in manufacturing processes to detect signs of abnormalities and facilitate investigation of the causes.

The previous system detected anomalies of measured values and estimated possible causes from many candidates related to the manufacturing processes. Possible causes were suggested in the order of likelihood scores, however, if multiple causes were related to one another, many possible causes were suggested with high scores. In this case, skilled engineers versed in their relationships needed to be involved to narrow down the causes, so it was necessary to upgrade the system to also allow even unskilled engineers to do so.

With this in mind, we have developed a cause estimation method that automatically narrows down possible causes, considering their relationships. It works in the following three steps:

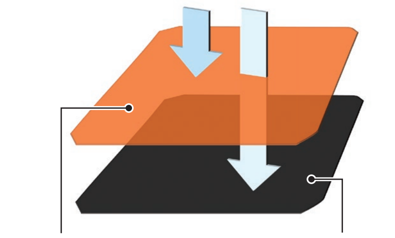
Step 1: The relationships among possible causes are determined based on data.

Step 2: Major causes that have a significant impact on the anomalies of measured values are identified.

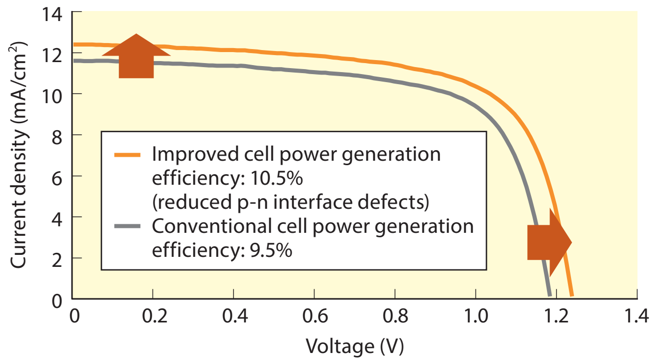
Step 3: Proximate causes that affect identified major causes are determined based on their relationships. The major causes and proximate causes are suggested with effect scores.

Compared with the previous system, the new system has reduced the number of suggested causes to 1/10th the previous number on average, facilitating cause investigation without skilled engineers.

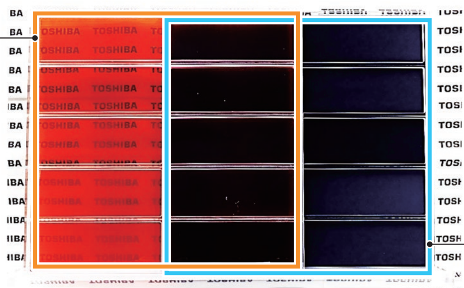
1.10 Improving Characteristics of Cu_2O Cells to Achieve High-Efficiency Tandem Solar Cells



Schematic diagram showing structure of tandem solar cell with transparent Cu_2O cell



Improving current-voltage (IV) characteristics of Cu_2O cells by reducing defects at p-n interface



* Area of Cu_2O cell that generates electricity is 125×42 mm, large enough for practical applications.

Two arrays of large Cu_2O cells in development (orange) overlapping two arrays of commercially available Si cells cut to same size as Cu_2O cells (light blue)

Toshiba Corporation is developing a tandem solar cell capable of generating significant electricity per unit area that consists of a cuprous oxide (Cu_2O) solar cell stacked on a silicon (Si) solar cell. In 2019, we developed a transparent Cu_2O cell which would be the key to achieving practical tandem solar cells. A milestone for tandem solar cells with 30% power conversion efficiency, is 10% power conversion efficiency for the Cu_2O cell.

We have now succeeded in increasing the power conversion efficiency to 10.5%, the world's highest yet achieved for a Cu_2O cell(*), which is greater than the milestone. This result was achieved by reducing defects at the p-n interface (p: p-type semiconductor, n: -type semiconductor).

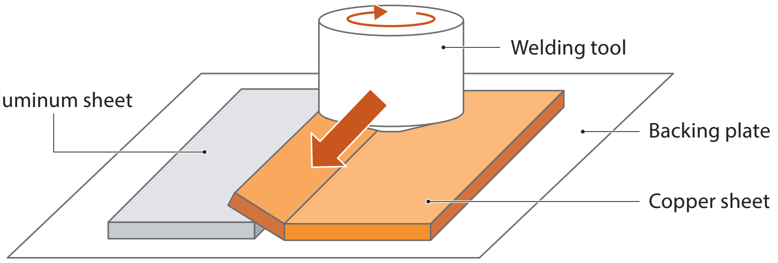
We will continue with efforts to develop larger Cu_2O solar cells at the same size as mass-produced Si solar cells, establish cell manufacturing technology by 2025, and demonstrate a practical-sized high-efficiency tandem solar cell. We will also promote tandem solar cells for mobility applications such as solar-powered EVs that do not require charging to contribute to the goal of a carbon-neutral society.

1. Research and Development

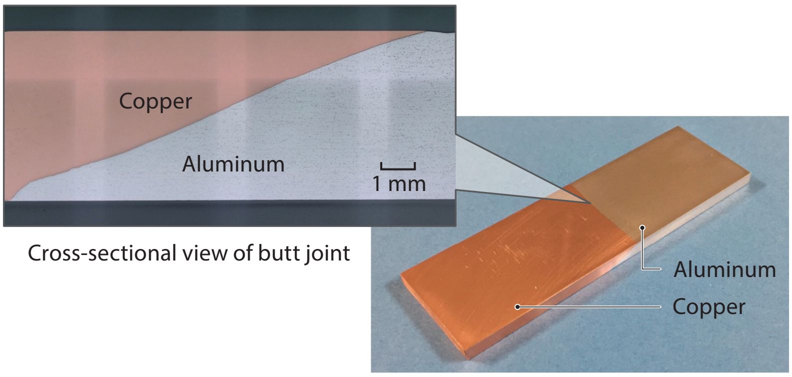
Some of the results reported herein were achieved through joint research with the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

(*) As of December 2023, for transparent Cu_2O solar cells (according to Toshiba Corporation research)

1.11 Contributing to Energy Saving with Butt Welding of Dissimilar Metal Sheets to Reduce Weight of Electrical Apparatus



Schematic showing butt welding method



Cross-sectional view of butt joint

External view

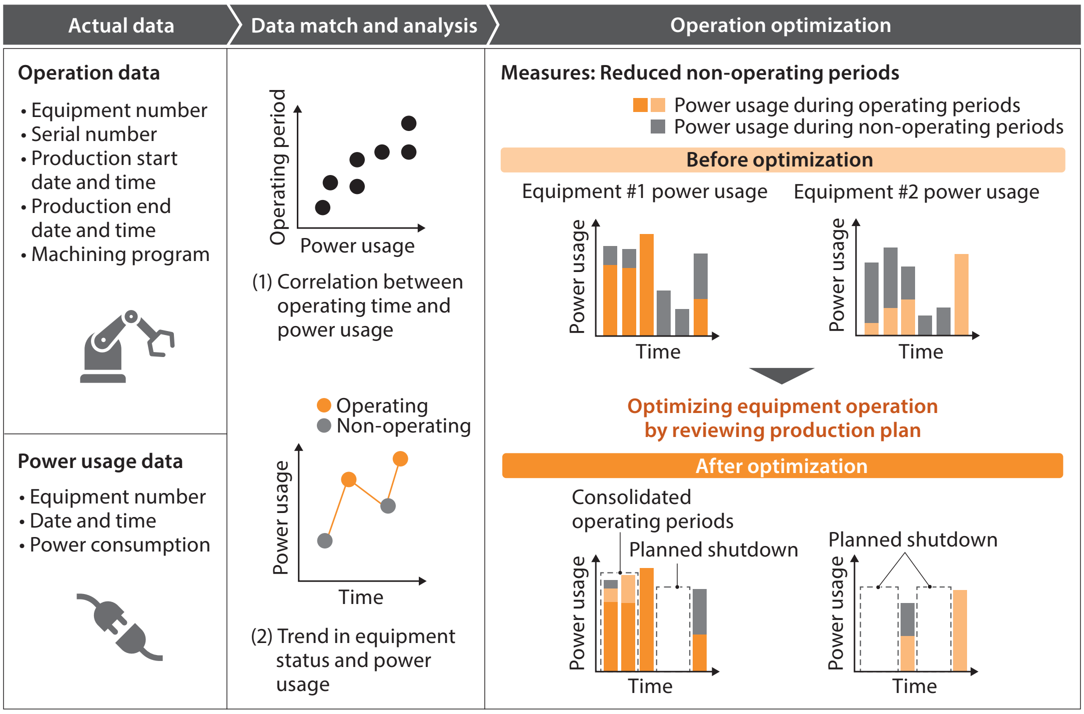
Butt-joined sheet consisting of copper and aluminum

The manufacturing industry is considering replacing some conductive copper parts with aluminum to reduce the weight of electrical apparatus and thereby reduce energy consumption. Doing so requires welding copper and aluminum. To obtain high-strength joints, a very thin, seamless intermetallic compound layer must be formed at the joint interface. Conventionally, this type of welding has been achieved by means of diffusion bonding, which requires a relatively long time and uses a significant amount of energy.

With this in mind, Toshiba Corporation has developed a butt welding technique which presses copper and aluminum sheets together with a slight overlap using a rotating welding tool. The resulting frictional heat causes eutectic melting of copper and aluminum, the generated melt is immediately pushed out of the joint interface, and the overlapping portion deforms into a butt joint. A high-strength aluminum-copper joint can be obtained by forming an inclined interface with a very thin (under 2 μm), seamless intermetallic compound layer.

The new welding technique consumes less energy than the conventional method, and because it requires neither vacuum nor an inert gas atmosphere, it can be easily integrated into the equipment assembly process. It is expected to be applied to electric motor, generator, vehicle equipment, busbar, and terminal block assembly.

1.12 Equipment Operation Optimization Contributing to Reduced GHG Emissions



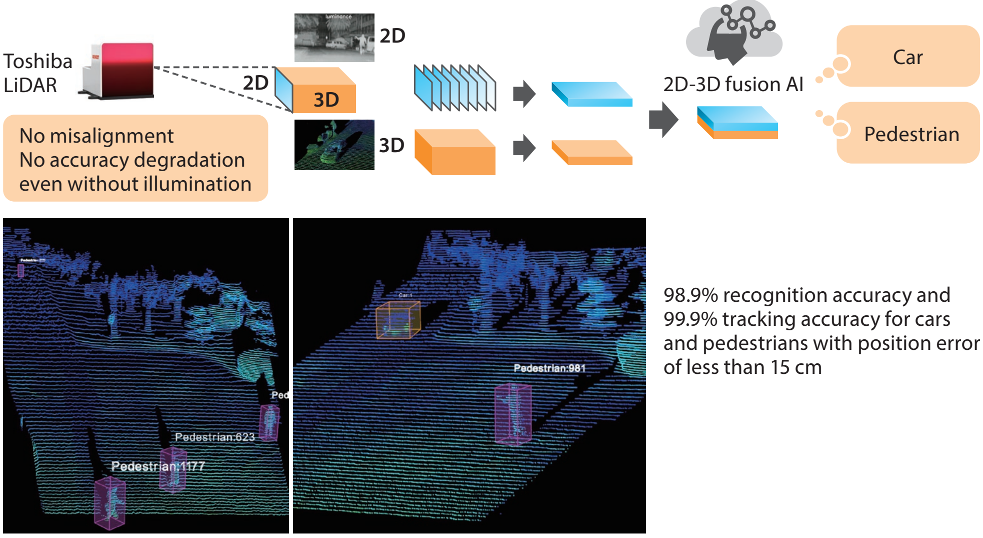
Machine operation optimization via data analysis to reduce GHG emissions

Adhering to the Basic Commitment of the Toshiba Group, “Committed to People, Committed to the Future,” we are committed to reducing GHG emissions. To accomplish this in the manufacturing process, Toshiba Corporation visualized standby power consumption during operating and non-operating periods by matching and analyzing operating and power usage data.

Using this approach, we analyzed the relationship between operating periods and power usage as well as changes to power usage according to equipment status. To verify measures for reducing non-operating periods, we reviewed production plans to consolidate equipment operation periods and scheduled planned shutdowns.

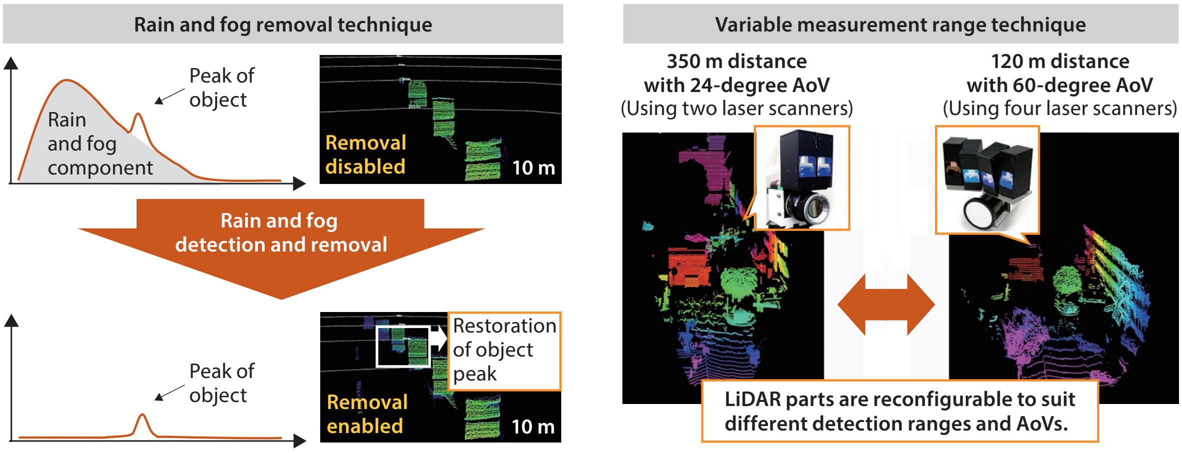
We have confirmed that GHG emissions can be reduced by 64% during non-operating periods by applying this method to machining lines, and we aim to promote it to achieve substantially reduced emissions.

1.13 LiDAR Technique for Spatial Digital Twins



* Results of demonstration for car driving 50 m to 115 m away, and pedestrian walking 80 m to 110 m away from LiDAR

Detection and tracking of pedestrians and cars using fusion AI for 2D and 3D data



Rain and fog removal technique and variable measurement range technique

Light detection and ranging (LiDAR)(*1), which allows three-dimensional (3D) recognition of target objects, can be used to construct spatial digital twins(*2) and thus helps improve efficiency in various industries, for example, via automating mobility vehicles and optimizing manufacturing and logistics lines.

Because it is difficult to recognize and track objects accurately using only 3D LiDAR data, conventional 3D recognition techniques combine cameras and LiDAR sensors. However, data from cameras and LiDAR sensors cause spatial and temporal misalignment, resulting in recognition accuracy degradation. Other issues include accuracy degradation in adverse weather conditions such as rain and fog and the occurrence of blind spots due to constraints of installation locations.

To solve these issues, Toshiba Corporation has developed a 2D-3D fusion artificial intelligence (AI) technique that integrates 2D and 3D data obtained solely from LiDAR sensors without using cameras, and has achieved the world's leading object recognition accuracy of 98.9% and object tracking accuracy of 99.9%[(*3)]. The new technique enables the construction of spatial digital twins, eliminating the need for many cameras.

In addition, we have developed a rain and fog removal algorithm to remove only the rain and fog components from sensor data, more than doubling the maximum detection distance in severe rain and dense fog. We have confirmed that the algorithm provides a maximum detection distance of 40 m in heavy rain of 80 mm/h. We have also developed a variable measurement range technique that makes it possible to change LiDAR's detection range and angle of view (AoV) by changing only the number of laser scanners and the receiving lens configuration. This has resulted in detection distances of 350 m with a 24-degree AoV and 120 m with a 60-degree AoV (approximately six times those of conventional systems).

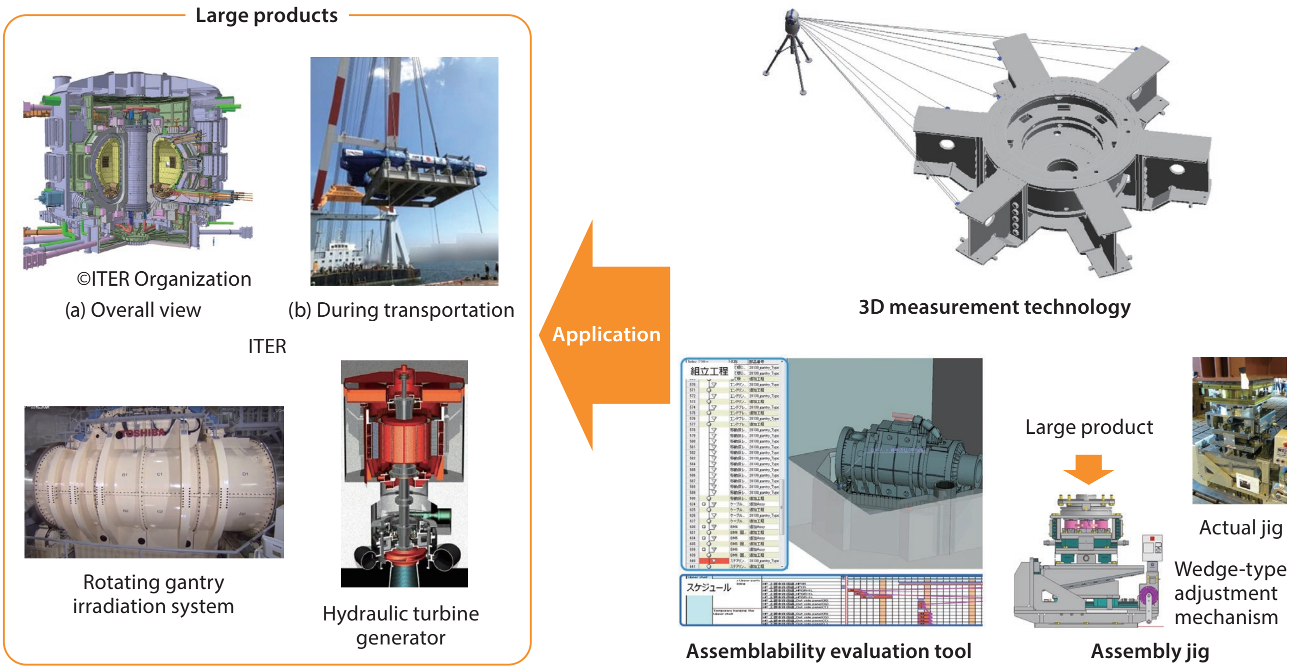
We will promote the widespread use of LiDAR systems to contribute to a safer, more secure society with infrastructure resilience.

(*1) A laser-based technology that measures the distance to objects to produce 3D images

(*2) A technology that identifies the position and movement of objects in space

(*3) As of November 2023 (according to Toshiba Corporation research)

1.14 Digital Twin Technology to Improve Manufacturing Accuracy and Reduce Costs of Large Products



Digital twin technology applied to large products

A digital twin is the virtual representation of a real-world physical product and helps streamline product development, manufacturing, and operations. A digital twin also helps to improve quality and reduce the cost of physical products.

To help reduce the cost and time required to assemble and install large products with a high degree of precision, Toshiba Corporation leverages three digital twin solutions: (1) high-precision 3D measurement technology, (2) an assemblability evaluation tool to visualize the assembly process in a virtual space, and (3) an assembly jig that makes it possible to assemble physical products as simulated in a virtual space. Three examples are given below.

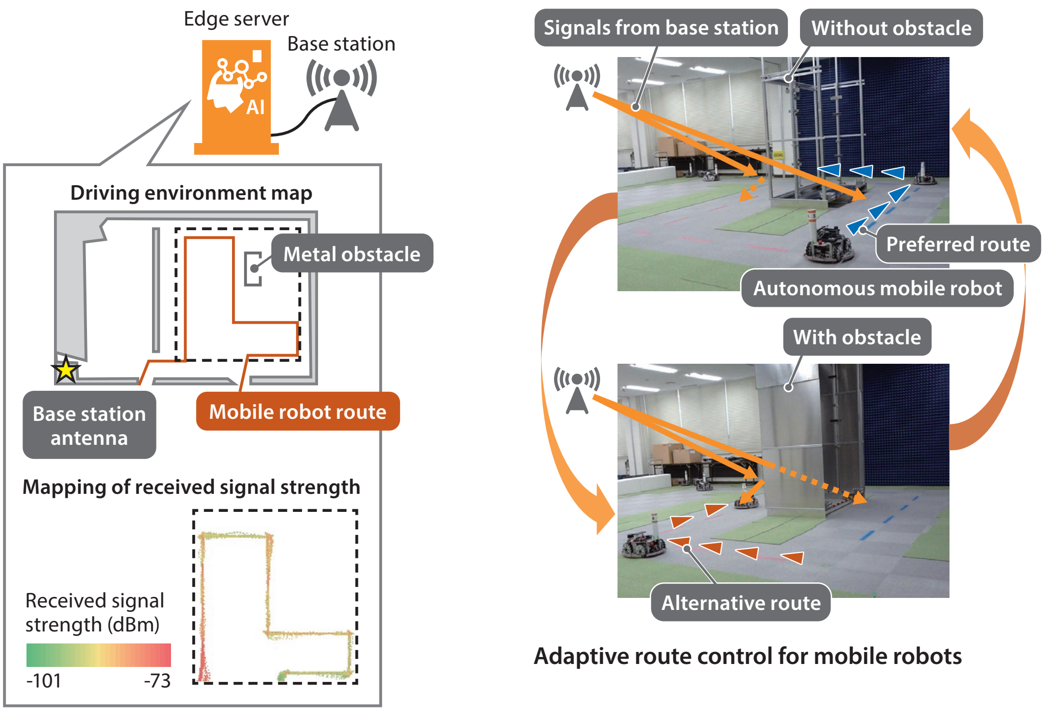
First, Toshiba Energy Systems & Solutions Corporation participated in the International Thermonuclear Experimental Reactor (ITER) project for scientific demonstration of fusion energy, and manufactured four toroidal coils, each 16 meters long, 10 meters wide, weighing 300 tons. Product specifications required an assembly accuracy of ±0.1 mm. Conventionally, a considerable amount of work hours were necessary to check the assembly of large parts. The new portable measuring machine incorporating 3D measurement technology makes it possible to check the assembly in a virtual space, reducing the workload required to check physical toroidal coil assemblies. An assembly jig with a wedge-type adjustment mechanism makes it possible to adjust the position of large parts with an accuracy of ±0.1 mm while supporting their weight.

Second, to install hydraulic turbine generators, Toshiba Energy Systems & Solutions Corporation previously needed to take many measurements for high-precision positioning. Traditionally, measurements were taken on-site by skilled workers using manual tools. We have now applied 3D measurement technology to develop a system that guides operators to the correct position derived in a virtual space, making it possible to reduce the time required for an assembly check.

Third, Toshiba Energy Systems & Solutions Corporation outsources the installation of rotating gantry irradiation systems to external companies. In the past, it was difficult to maintain the quality of this process because of varying capabilities, so we have employed an assemblability evaluation tool to study the installation process in virtual space, eliminating the risk of incomplete assembly and ensuring the quality of installation work.

Next, we will expand the use of digital twin technology to other large products and promote application throughout the company.

1.15 Mobile Robot Control Technology Using Private 5G to Improve Warehouse Transport Efficiency



Processing on edge server using private 5G

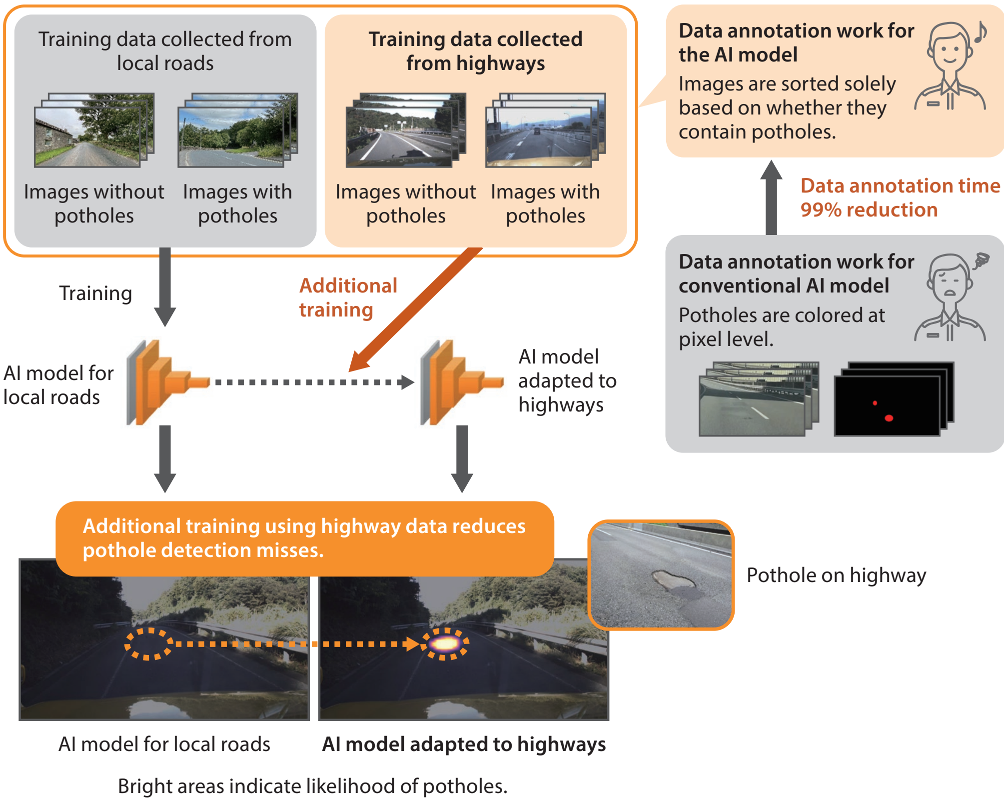
Adaptive route control for mobile robots

Private fifth-generation (5G) cellular network technology is attracting attention as a means of building highly reliable networks. With this in mind, Toshiba Corporation has developed technology for real-time group control of mobile warehouse transport robots. This is handled via private 5G from an edge server on which commonly used mobile robot functions are installed. We have also developed a technique to adaptively select robot driving routes while estimating environmental changes in a warehouse.

We deployed a private 5G system with an edge server which allows communication with 10 mobile robots. In an experiment, the edge server controlled mobile robot routes, avoiding metal obstacles with varying heights that emulate stacked pallets in the warehouse. For route control, the edge server utilized a map of the received signal strength to identify (1) changes in line-of-sight conditions between the base station and mobile robots at the backside of the obstacle and (2) variations in the strength of a signal reflected from the front of the obstacle. Measurement results indicate that adaptive route control improves transport efficiency by up to 9.3%.

The results reported were achieved in the "Research and Development Project of the Enhanced Infrastructures for Post-5G Information and Communication Systems" (JPNP20017) commissioned by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

1.16 Real-Time Detection of Highway Potholes Using Weakly Supervised AI Model for Image Anomaly Detection



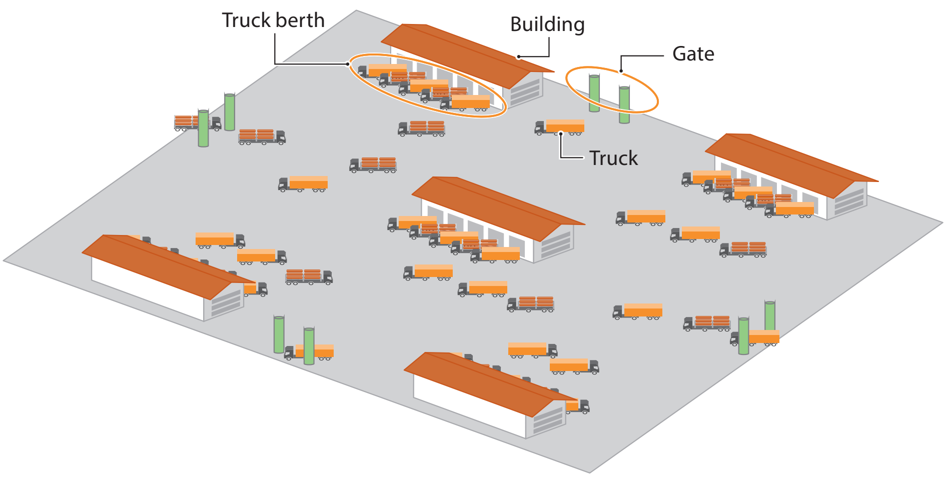
Results of pothole detection using new weakly supervised AI for image anomaly detection

Using AI for image anomaly detection can potentially save time and labor during daily highway inspections. However, training is required to develop an AI model that is adaptable to a variety of inspection targets. Annotating anomaly locations in training images at the pixel level entails a considerable amount of effort, however.

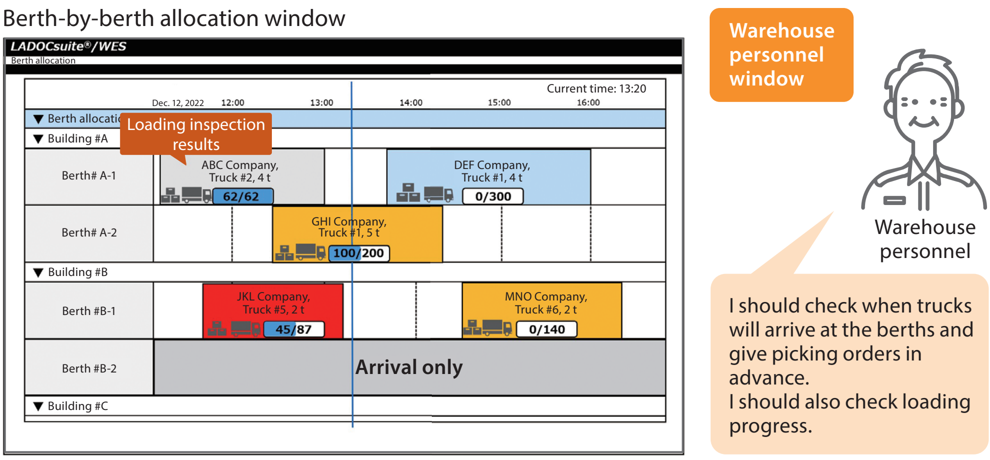
To solve this issue, Toshiba Corporation has developed a weakly supervised AI model that can be trained with image-level annotations, reducing annotation time by 99%. We conducted a demonstration experiment to detect potholes on a highway that required urgent repairs, confirming that the new AI model works at a speed of 26 frames per second and can detect pothole locations in real time while driving at a speed of 80 to 100 km/h. Furthermore, when we used highway data for additional training of an AI model pre-trained with local road data, the pothole detection accuracy increased from 61.25% to 84.22%. This result confirms the effectiveness of additional training using data collected from the actual environment.

We will continue with demonstration experiments in collaboration with Toshiba Digital Solutions Corporation and Central Nippon Expressway Co. Ltd. with the goal of practical use in 2024.

1.17 Truck Berth Scheduling for Large Distribution Warehouses to Reduce Truck Driver Waiting Time



Target application of truck berth scheduling: Large distribution warehouse (with 4 gates, 5 buildings, and 25 berths)



Example of output image of berth-by-berth truck scheduling

To support work style reforms being implemented in Japan's logistics and transportation industries, the Toshiba Group is developing a warehouse execution system (WES) for distribution warehouses. Part of this effort includes launching a truck berth(*) scheduling service which allocates berths and time slots to trucks for loading and unloading operations. It helps reduce driver wait time at warehouses, allowing them to stick to their departure schedules. It is beneficial for large warehouses with several gates, and buildings with multiple berths where each truck driver visits several buildings in a single trip to load and unload freight. The fast heuristic algorithm for this scheduling service has the following benefits:

(1) Minimizing the wait time before using berths and minimizing delay time for departure improves truck driver satisfaction.

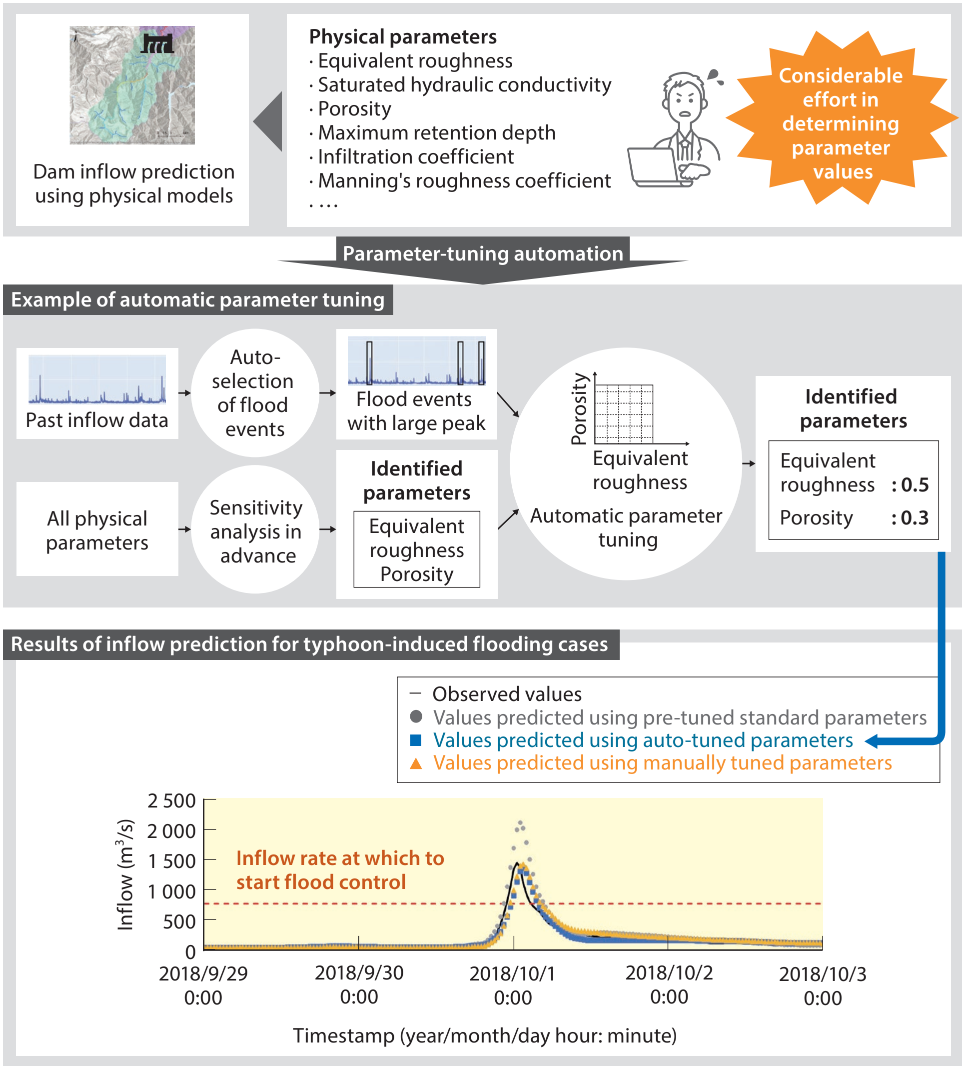
(2) Optimizing the order of visiting several buildings by each truck driver makes it possible to reduce warehouse congestion.

(3) Analyzing actual loading and unloading operations for various packing styles and quantities makes it possible to estimate the necessary time with a high degree of accuracy.

We deployed this algorithm on the cloud for utilization across the Toshiba Group.

(*) Parking space in front of a warehouse building where trucks are loaded and unloaded

1.18 High-Precision Dam Inflow Prediction Using Auto-Tuned Parameters During Floods



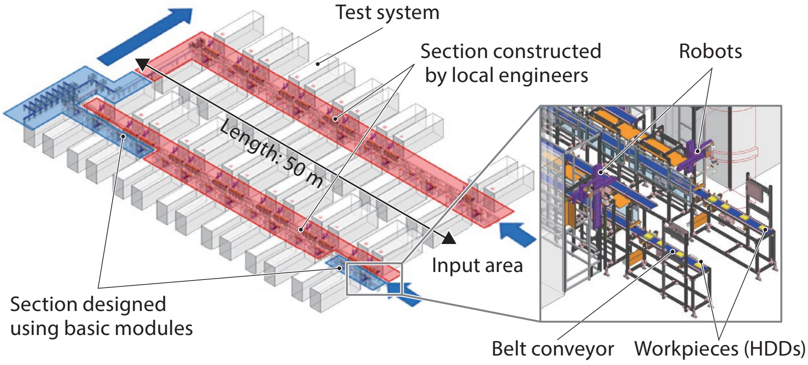
Overview of dam inflow prediction with automatic parameter tuning

Floods caused by heavy rainfall have increased in recent years, and both national and local governments have been working on dam inflow prediction and reviewing dam gate operations to prevent downstream flooding. Physical models have mainly been used for inflow prediction during floods, and numerous model parameters have traditionally been adjusted manually to improve prediction accuracy.

Toshiba Corporation has developed an automatic parameter-tuning technology, enabling high-precision dam inflow prediction. First, we identified a small number of parameters that significantly affect flood events through a sensitivity analysis. In the parameter-tuning process, several flood events were selected automatically from past data to determine parameter values using a technique known as a grid search. Our evaluation of dam inflow data revealed that automatic parameter tuning provides higher prediction accuracy (a 30% reduction in mean absolute error) than when using standard parameters. Furthermore, the accuracy obtained with automatic parameter tuning is equivalent to that achievable with manual tuning.

As a next step, we will apply the new technology to a dam gate control system and continue with verification tasks.

1.19 Automatic Transport System Offering Both Versatility and Economic Benefits



HDD test process

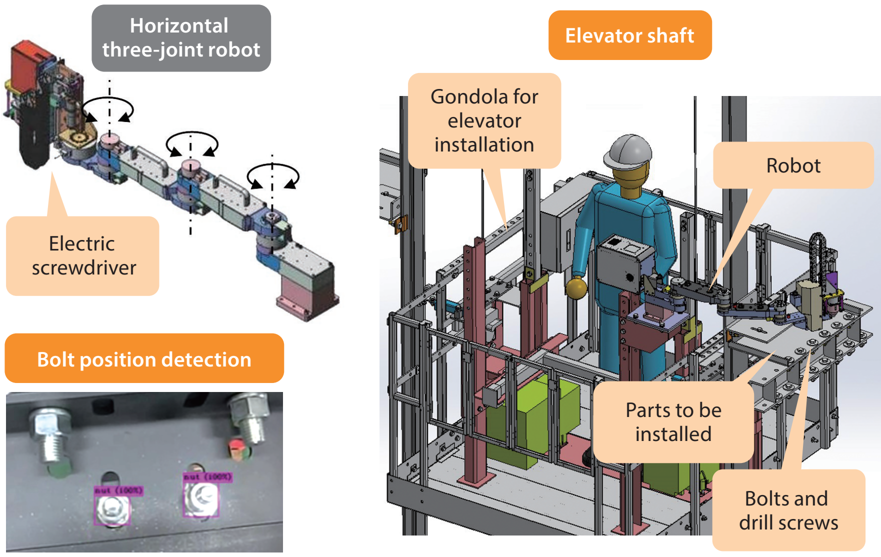
Automatic transport system (input area)

Toshiba Corporation has developed an automatic transport system for the test process at an overseas hard disk drive (HDD) factory. The test process originally required many test systems installed in a large area measuring more than 50 meters in length. It was difficult, however, to balance the throughput of these test systems as human operators needed to transport, load, unload, and sort workpieces manually.

To solve this problem and eliminate manual operations, we deployed the new automatic transport system. We succeeded in adjusting the throughput balance among test systems, thereby reducing the numbers of operators and work-in-process units by approximately 75%. We also developed basic modules for conveyors and robots in Japan, which were combined to build a versatile, automatic transport system at the test area of an overseas HDD factory. This helped to reduce test system costs and improve the return on investment.

We will continue to develop automation technologies to improve production line efficiency.

1.20 Portable Assistant Robot for Elevator Installation



New robot and example in gondola for elevator installation

Automatic installation of drill screws (reproducing skills of experienced operators)

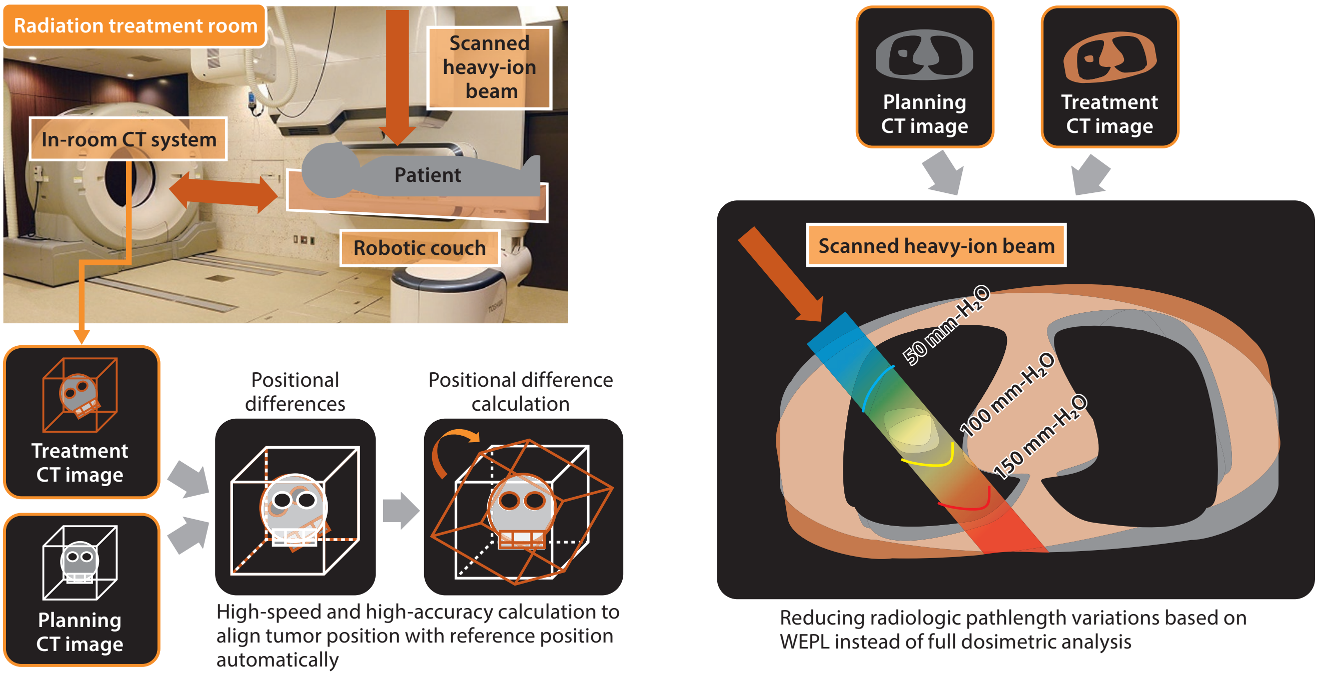
With recent shortages of skilled elevator installation technicians, demand for labor-saving solutions has grown. To facilitate elevator installation in different buildings, the equipment must be easy to carry and set up.

To meet this demand, Toshiba Corporation has developed an assistant robot for elevator installation that weighs only 10 kg, and can be carried easily. Its drill-like tip can tighten bolts and drill screws while controlling the pressing force and rotation direction of an electric screwdriver to emulate the motion of human technicians. Despite its light design, the robot tip is sturdy enough to withstand high loads. Furthermore, the new robot leverages deep learning using computer graphics to detect the positions of pilot holes for drilling without prior adjustment even at new installation sites.

At present, we are conducting a field evaluation and gathering technician feedback to further improve the robot's functionality and reliability with the goal of practical application.

1. Research and Development

1.21 Optimizing 3D CT Image Registration for Heavy-Ion Radiotherapy



(a) CT image registration algorithm

(b) CT image registration algorithm for adjusting position where charged particle beam stops to planned target distal surface

Schematic drawing of 3D patient positioning technology for heavy-ion radiotherapy

Heavy-ion radiation therapy is emerging as a new type of radiotherapy that irradiates and kills cancer cells with heavy-ion beams. It offers higher quality of life (QOL) than conventional X-ray radiotherapy because of a shorter treatment period and fewer physical side effects.

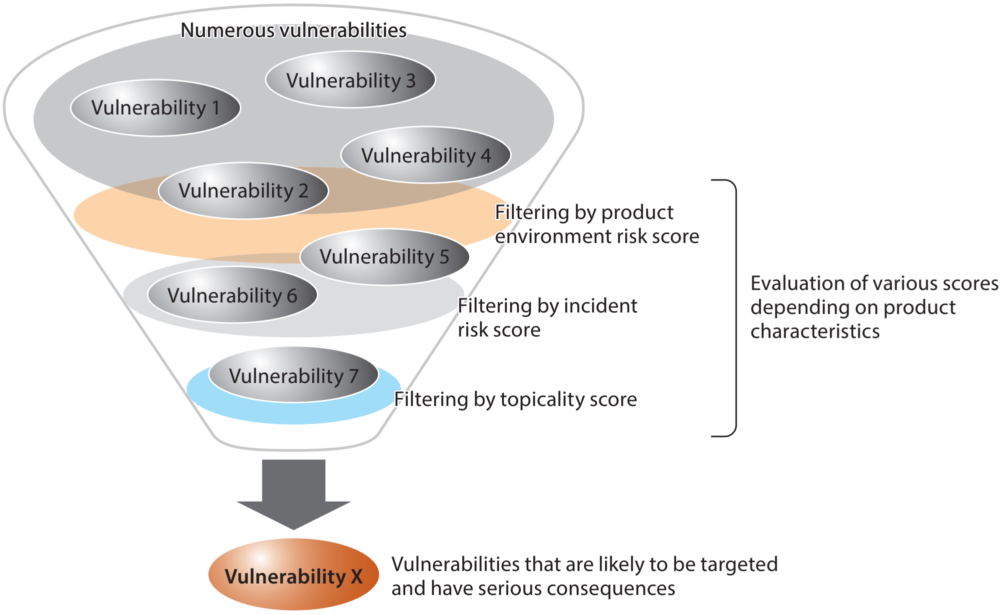
Important steps in radiotherapy include accurate patient setup and target localization according to the treatment plan. To align the patient's position accurately, a 2D-3D registration technique is employed to measure the similarity between two-dimensional (2D) fluoroscopic images captured at the beginning of treatment and a 3D planning computed tomography (CT) image. This technique has recently been integrated with setup software.

The number of radiotherapy treatment rooms equipped with an in-room CT system is increasing slowly. Such systems use a 3D-3D image registration algorithm to achieve more accurate irradiation than the 2D-3D algorithm. The issue with the 3D-3D registration algorithm is that it is more time-consuming.

To resolve this issue, Toshiba Corporation is developing a fast 3D-3D auto registration algorithm in collaboration with the National Institute of Quantum Science and Technology (QST). This algorithm runs on a graphical processing unit (GPU) for parallel processing to calculate the direction in which pixel intensity differences between two CT images decrease.

Furthermore, we are developing an algorithm that minimizes differences between actual and planned beam ranges. An evaluation of the water equivalent pathlength (WEPL, mm-H_2O) would be more efficient than a full dosimetric analysis in terms of computational time. The time required for intensity- and WEPL-based computation is not expected to be significantly different from that of the 2D-3D registration algorithm. We plan to achieve practical use of the 3D-3D registration algorithm around 2025.

1.22 Technology for Assessing Software Vulnerability Risks



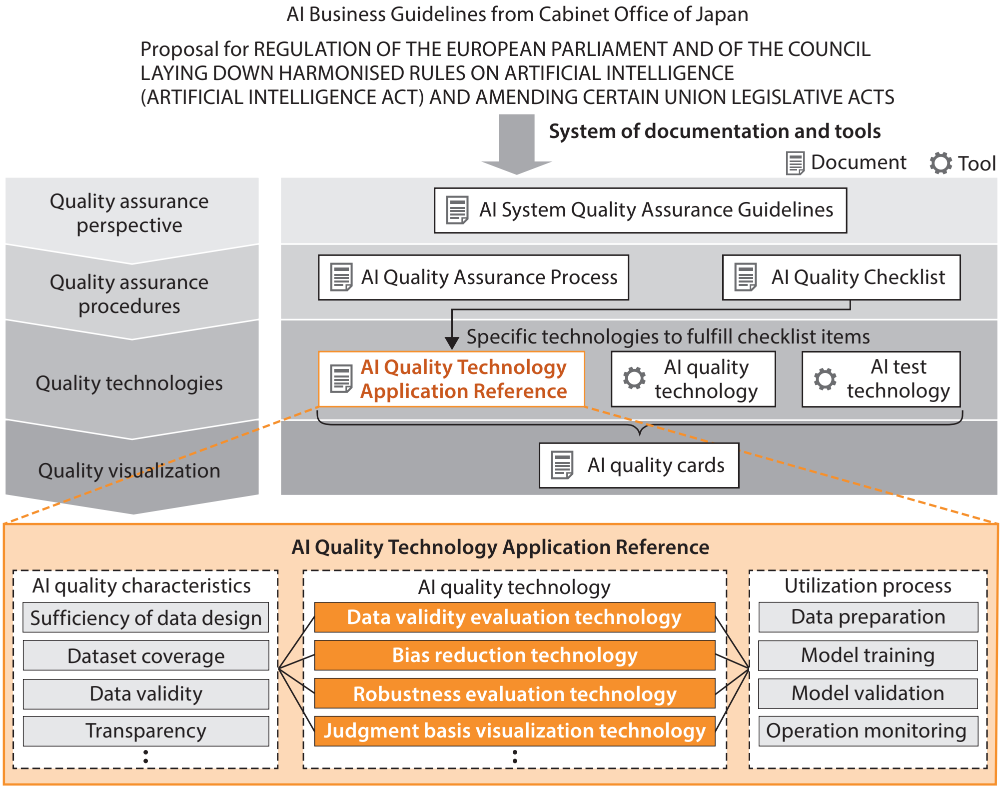
Overview of vulnerability risk assessment technique

Tens of thousands of software vulnerabilities are reported every year, and some allow malicious manipulation of a product's embedded software. With this in mind, Toshiba Corporation has developed risk assessment technology which allows product developers to identify and prioritize fixing critical vulnerabilities. To assess vulnerability severity, the technology employs three types of risk scores: (1) product environment risk score, (2) incident risk score, and (3) topicality score.

The product environment risk score depends on the product usage environment and implemented security measures. The incident risk score is determined by the presence of past attacks against vulnerabilities and whether any attack programs are publicly available. The topicality score measures vulnerability media reporting and web posting status, or in other words, the degree to which a given vulnerability is likely to attract the interest of our customers. These scores make it possible to detect changes in risk early and prevent security incidents.

An evaluation of approximately 40 000 vulnerabilities allowed us to narrow down the number of high-priority vulnerabilities to 1/25th of those identified by the Common Vulnerability Scoring System (CVSS), confirming that the new risk assessment technology missed no critical vulnerabilities. This indicates that we need to address only several vulnerabilities in each product per month. We will apply this technology to our vulnerability handling process to demonstrate its effectiveness.

1.23 AI Quality Technology Application Reference Enabling Practical Implementation of AI Quality Management



Roles of AI Quality Technology Application Reference for AI quality management within system of documentation and tools

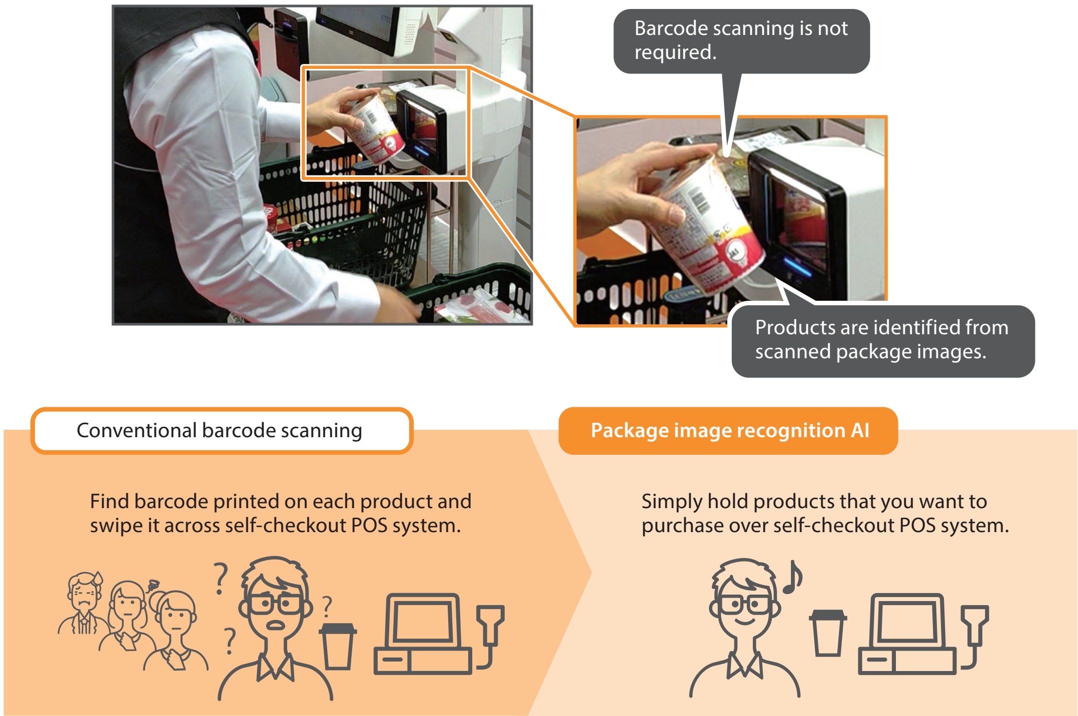
Momentum is growing to strengthen the governance of AI, including a move on the part of the Cabinet Office of Japan to consider establishing AI Business Guidelines. With this in mind, Toshiba Corporation has developed a comprehensive documentation and tool system for AI quality management. Central to this framework is the AI Quality Technology Application Reference, which catalogs technologies for evaluating and improving AI quality and corresponds to items on the AI Quality Checklist.

The AI Quality Technology Application Reference categorizes and organizes AI quality technologies from the perspectives of the AI utilization process and AI quality characteristics (defined in the Machine Learning Quality Management Guideline from the National Institute of Advanced Industrial Science and Technology (AIST) of Japan). Four stages of the AI model lifecycle are defined in the AI utilization process: data preparation, model training, model validation, and operation monitoring. AI quality characteristics include data validity and transparency. The AI quality technologies, including our proprietary methods, are mapped to their categories. For each technology, we describe the quality challenges that it addresses, effects, usage methods, applicable data types, and AI model types.

1. Research and Development

The AI Quality Technology Application Reference allows AI developers and operators to more easily find the technologies necessary to evaluate and improve AI quality, thereby enhancing the efficiency and effectiveness of AI quality management.

1.24 Package Image Recognition AI for Self-Checkout POS Systems to Identify Products without Scanning Barcodes



Identifying products scanned with self-checkout POS system by capturing images

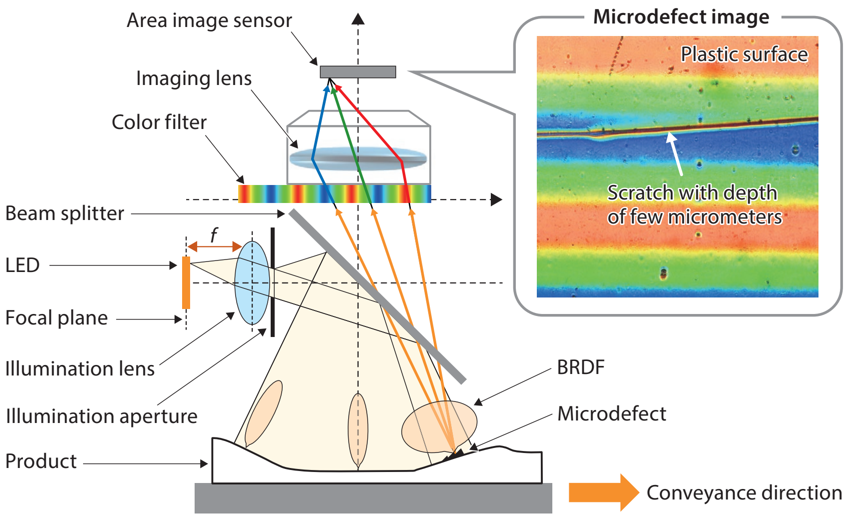
Self-checkout point-of-sale (POS) systems are attracting attention as a means of making shopping more convenient and alleviating labor shortages at stores. However, customers unfamiliar with POS operations tend to struggle with barcode scanning, leading to long checkout times, necessitating easy-to-use self-checkout POS systems.

With this in mind, Toshiba Corporation has developed an AI model for self-checkout POS systems that recognizes product packages from scanned images instead of using barcodes to identify products. This AI model requires no more processing time than traditional barcode scanning and eliminates the need for customers to find barcodes.

An experiment using a dataset covering approximately 6 000 products sold by supermarkets confirmed that the new AI model correctly identified roughly 97% of the target products. The new AI model was also able to offer several likely candidates for the products that it failed to identify. Furthermore, new products can be added simply by taking photographs with the scanner of a self-checkout POS system, and we confirmed that about 90% can be identified.

We will collaborate with Toshiba Tec Corporation to incorporate the new AI model into self-checkout POS systems in order to contribute to an improved customer experience and greater efficiency.

1.25 One-Shot BRDF Optical Inspection for Curved Surfaces



LED: light-emitting diode

Schematic of optical system and example of image showing microdefects

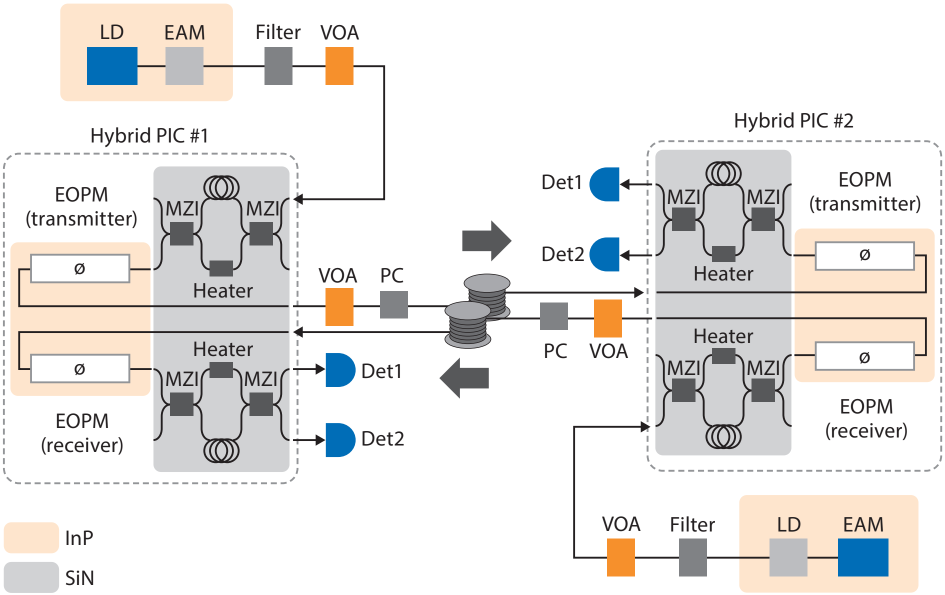
For quality control of automobile and many other manufacturing processes, there is an increasing need for high-speed non-contact inspection of microdefects on product surfaces that does not rely on visual inspection by skilled workers.

With this in mind, Toshiba Corporation has developed an imaging technology called one-shot bidirectional reflectance distribution function (BRDF) to capture subtle changes in the direction of reflected light as color changes, effectively visualizing microdefects. However, inspecting microdefects on curved surfaces has proved challenging because the reflected light does not return to an imaging device.

To solve this issue, we have developed an optical system that projects point-spreading light onto a curved surface to instantly determine the extent of reflected light angle broadening from each point of the surface using a multicolor filter. This system can detect microdefects with height differences of a few micrometers or less on surfaces with a maximum inclination of ±10° by capturing changes in a variety of colors.

This new technology enables identification of microdefects on curved surfaces of products traveling on a manufacturing line, making it possible to automate inspection and increase manufacturing efficiency.

1.26 Hybrid Photonic Integrated QKD Transceiver Chip



PIC: photonic integrated circuit
PC: polarization controller
MZI: Mach-Zehnder interferometer
VOA: variable optical attenuator
Det: single-photon detector
LD: laser diode
EAM: electro-absorption modulator
EOPM: electro-optic phase modulator

Configuration of bidirectional communication system using hybrid photonic integrated QKD transceiver chips

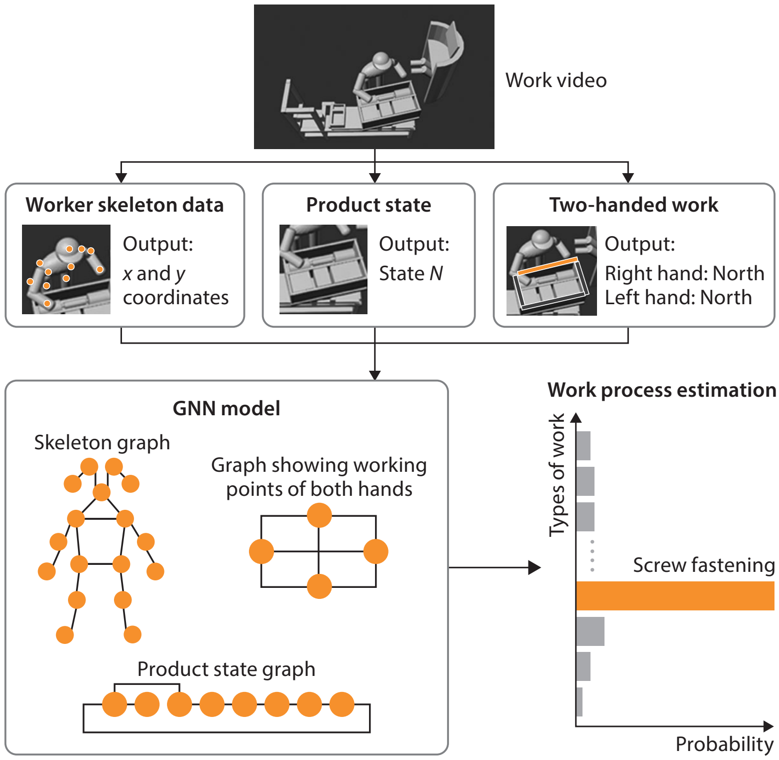
For widespread adoption of quantum internet services to succeed, the size and cost of quantum key distribution (QKD) systems must be reduced. In 2021, Toshiba Europe Limited demonstrated the world's first chip-based QKD system(*) using photonic integrated circuits consisting of an indium phosphide (InP) QKD transmitter (QTx), quantum random number generators (QRNGs), and a silicon nitride (SiN) QKD receiver (QRx).

We have now developed QKD transceiver chips (QTRx) that combine the QTx and QRx chips using hybrid photonic integration. The hybrid QTRx chip combines ultralow propagation losses and high-speed phase modulation.

We have achieved the longest chip-to-chip QKD link over 250 km of real fiber and the first bidirectional QKD using two QTRx chips with a combined secure key rate (SKR) of 2.4 Mbps and 15 kbps over 50 and 180 km fiber links. The hybrid QTRx chips also delivered high stability with up to 54 hours of continuous operation. Combined with a high level of reproducibility, the hybrid QTRx chips are promising devices for network-agile, mid-range QKD systems toward the realization of a quantum internet.

(*) As of October 2021 (according to Toshiba Europe Limited research)

1.27 Work Process Estimation Based on Worker Skeleton Data, Product States, and Working Points



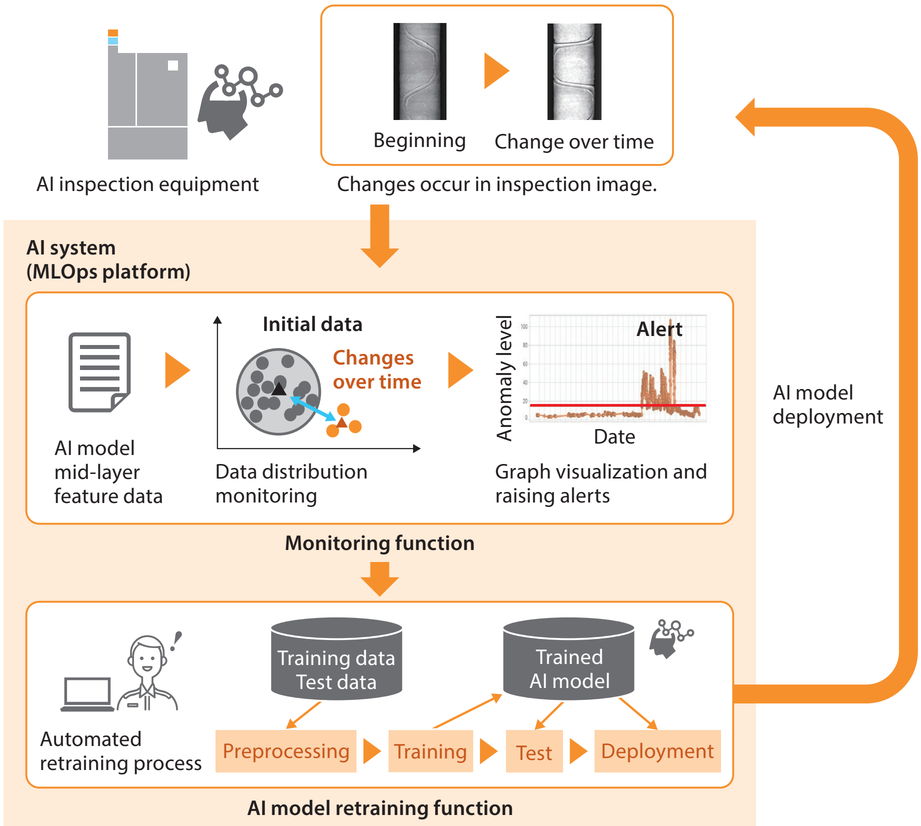
Work process estimation based on worker skeleton data, product states, and working points

Activities are conducted at most manufacturing sites to improve productivity by automatically collecting and analyzing manufacturing-related data. It is difficult, however, to collect data about manual assembly processes that depend on people due to their complexity and diversity.

With this in mind, Toshiba Corporation has developed a novel method to estimate work operations automatically and accurately by tracking three types of data: worker skeleton, product states, and working points. These data are extracted from video images captured at a work site. This method uses a graph neural network (GNN) as a learning model to capture detailed features, considering graph structures for each input. We evaluated the accuracy using data from nine workers in an assembly process consisting of 16 operations. The results indicate an accuracy of more than 85%, which is sufficient for practical application.

The next step is to apply this method to various products and services to automate collection of work data necessary for improvement activities.

1.28 Development of AI System Enabling Long-Term Maintenance of Quality Inspection Accuracy



Overview of AI system enabling long-term maintenance of quality inspection accuracy

Various factors can cause the accuracy of AI-based product quality inspection to deteriorate during operation, including material variation and changes of inspection equipment over time. To maintain inspection accuracy over the long term, it is necessary to monitor temporal changes in data and retrain an AI model when any signs of accuracy deterioration are detected.

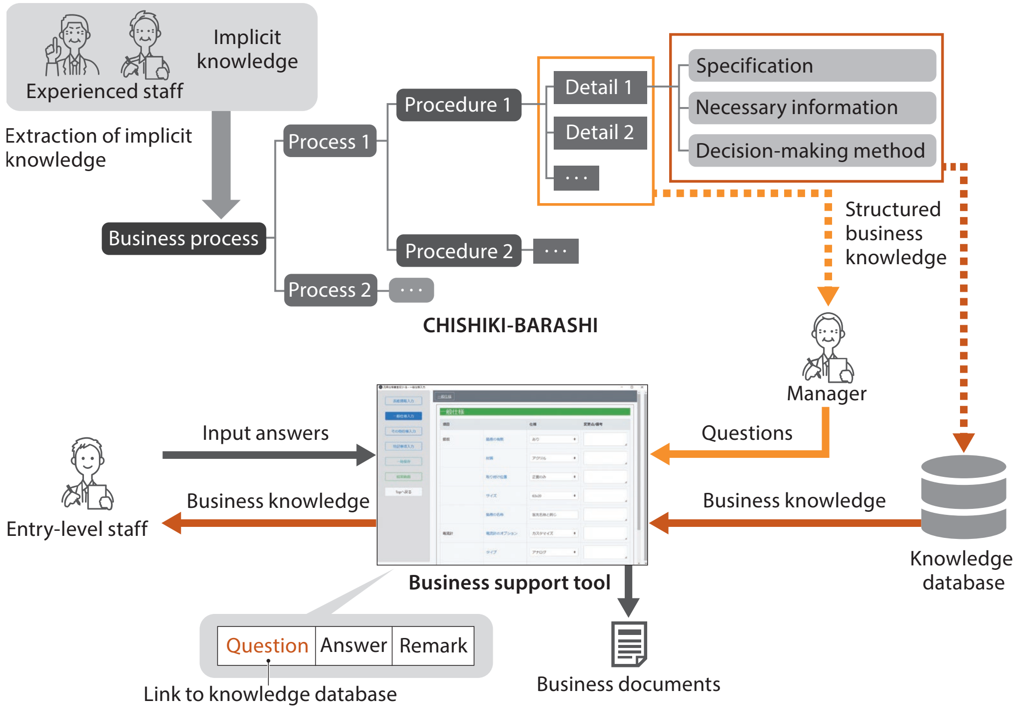
With this in mind, Toshiba Corporation has developed an AI system capable of retraining an AI model for visual inspection on a ceramic product manufacturing line. Implemented using our machine learning operations (MLOps) platform(*), the AI system monitors mid-layer feature data from the AI model, raises an alert in the event of data changes, and simplifies AI model retraining.

The new AI system succeeded in detecting data changes when inspection accuracy began deteriorating because of changes to the lighting angle that had occurred over 10 months of manufacturing operations and raised an alert within 30 minutes. We were then able to retrain the AI model in a timely manner to restore inspection accuracy.

The next step is to deploy the new AI system for various other inspection processes.

(*) A framework for managing the machine learning life cycle

1.29 Knowledge Utilization and Transfer Method Linking Business Support Tools and CHISHIKI-BARASHI



Overview of knowledge utilization and transfer system consisting of knowledge systematization and business support tools

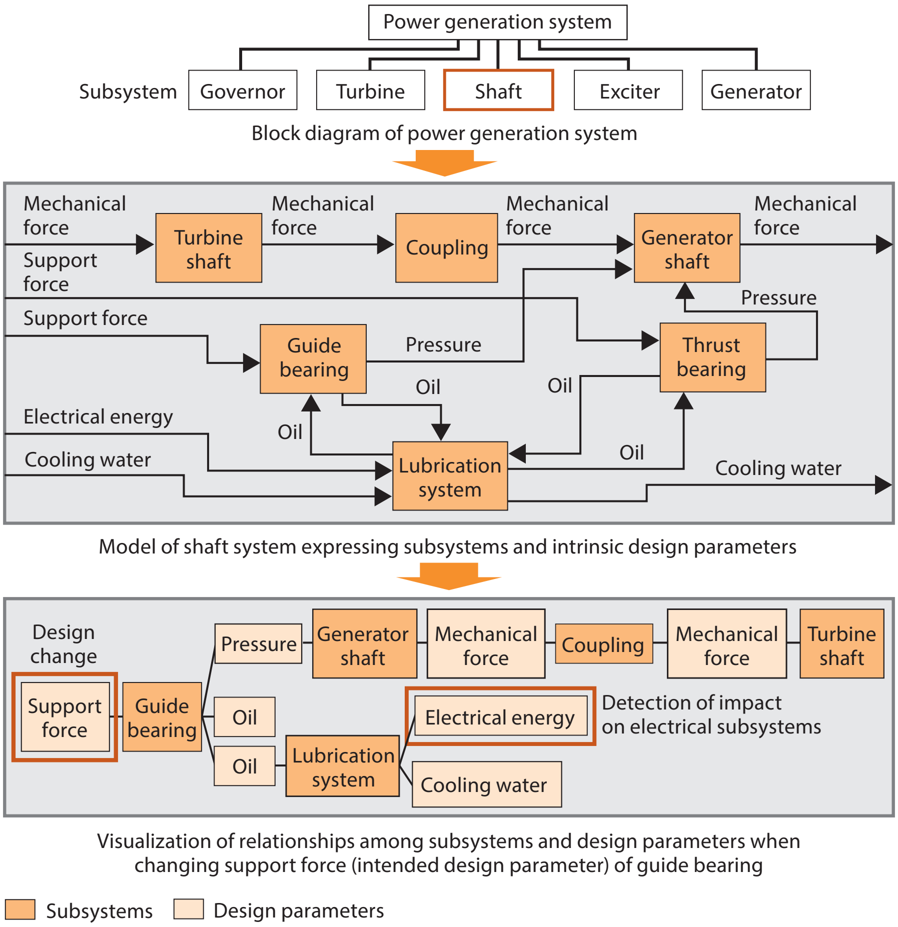
To ensure business continuity, it is important to build an environment that facilitates business operations and knowledge transfer from experienced to entry-level staff. Toshiba Corporation has developed a method to efficiently utilize business knowledge by linking business support tools with a methodology called "CHISHIKI-BARASHI."

CHISHIKI-BARASHI is used to promptly extract knowledge and decision-making insights, which tend to be implicit. This makes it possible to store the digitized information into a knowledge database with a layered structure. This knowledge database helps entry-level staff to improve their operational efficiency. However, they might still fail to try and search for useful knowledge, proceeding with business operations without applying knowledge. This situation could hinder the operational stability of an organization.

To solve this problem, we first standardized the format of business documents and developed a support tool for creating them. Then, we added another function to the tool to generate links to specific knowledge useful for each user. The tool therefore allows entry-level staff to create business documents efficiently while acquiring useful business knowledge. We leveraged the new tool to build an environment that efficiently empowers them with the right business knowledge at the right time.

We have applied the new methodology to social infrastructure business to improve operational efficiency, building an environment to transfer business knowledge in an organization.

1.30 Design Change Management Technique Using MBSE



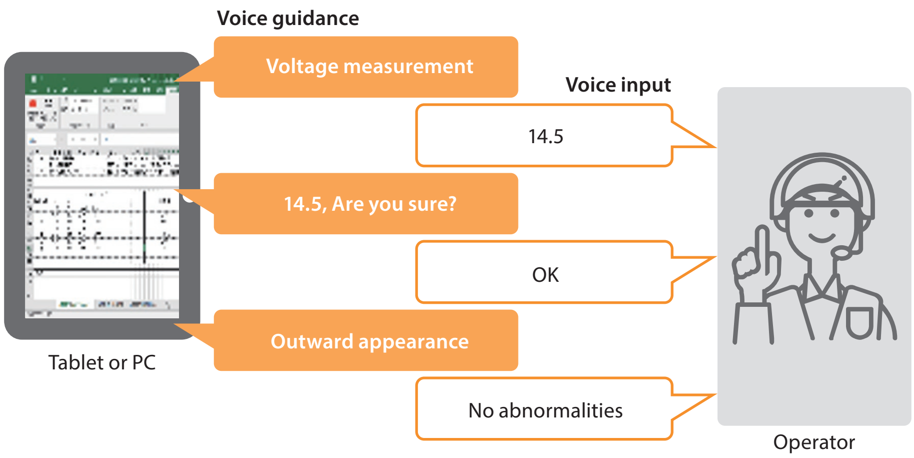
Design change management technique for visualizing relationships among parameters to estimate impact of changes

Design specifications for made-to-order products are determined according to customer requirements, including for electric power and social infrastructure products. It is crucial to modify the product design as customer requirements or design specifications change, however, it is practically impossible to manually track all changes as infrastructure systems require an extensive design process. Therefore, a consistent and efficient management technique that does not rely on human skills is necessary.

With this in mind, Toshiba Corporation has developed a design change management technique applying model-based systems engineering (MBSE), which uses systems modeling language (SysML) diagrams to describe a target product as a hierarchical subsystem model. We have applied this technique to a power generation system, successfully detecting the impact of mechanical parameter changes on its electrical subsystems.

The new technique can also be employed at the operation and maintenance stages to visually detect trouble-causing subsystems from the points of origin. Using the new technique at these stages of the product life cycle contributes to achieving a sustainable society.

1.31 Streamlined Inspection and Maintenance Using Voice-Interactive Form Input Tool with Speech Recognition Technology



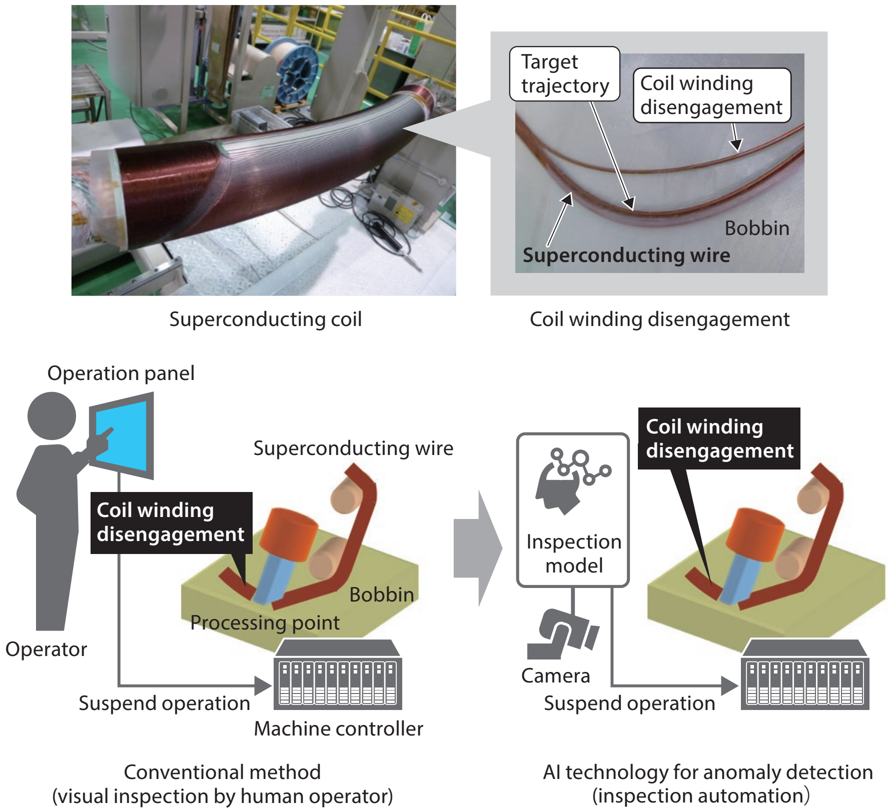
Voice-interactive form input tool

Inspection and maintenance results and measured data are sometimes recorded on paper forms and later entered in a computer system. To streamline this process, Toshiba Corporation has developed a voice-interactive form input tool incorporating AI-driven speech recognition technology. It operates as an add-on to spreadsheet software commonly used for creating forms and allows direct data voice input into electronic files. It provides voice guidance on work details and input fields following predefined steps, enabling operators to enter task results or measured data via voice.

The voice-interactive form input tool enables a single person to handle a two-person task, reduces manual data entry, and streamlines work with hands-free operation. It also provides safety instructions via voice to prevent any oversight in inspection and maintenance procedures and detects abnormal conditions by comparing voice input data with reference values, enhancing safety and work quality.

We have deployed the new voice-interactive form input tool at maintenance sites and manufacturing facilities, and plan to expand use in other work environments.

1.32 AI-Based Anomaly Detection Technology to Save Coil Winding Inspection Labor



AI technology for detecting coil winding disengagement

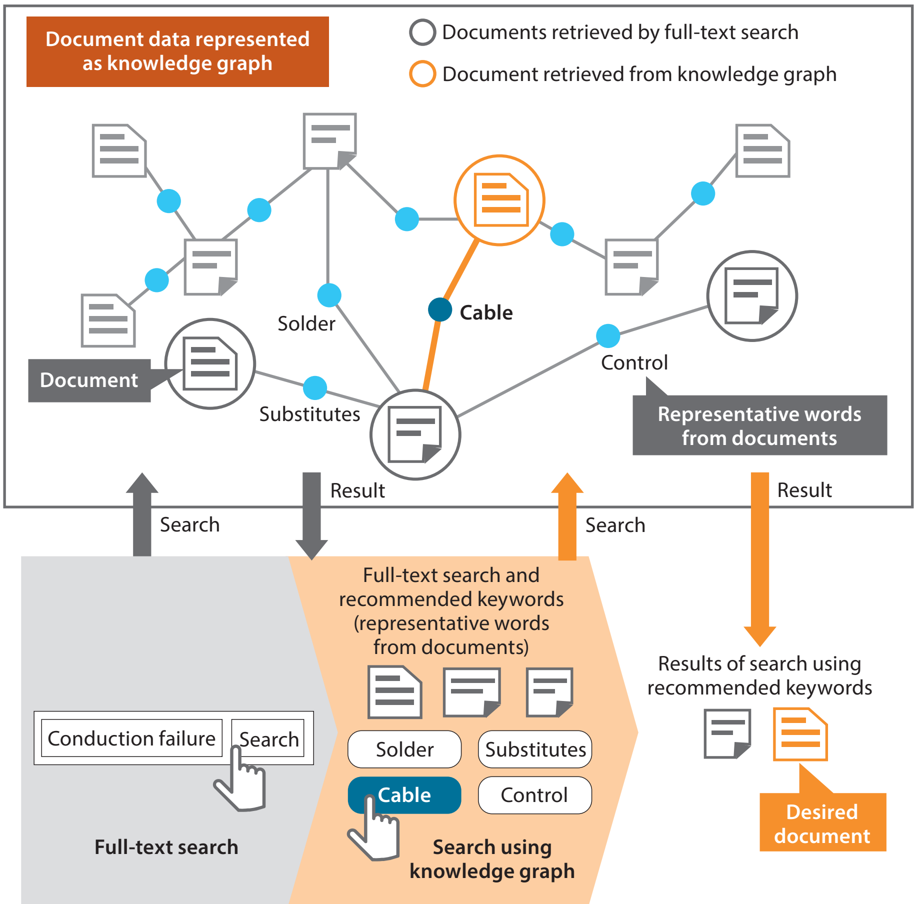
Toshiba Corporation has developed an AI-based anomaly detection technology to save labor required for inspection in the superconducting magnet winding process.

During the coil winding process, a superconducting wire is pressed and welded onto the surface of a bobbin using a winding machine. When doing so, insufficient welding can cause the superconducting wire to come off the bobbin surface. If this happens, operation of the coil winding machine must be suspended immediately to manually bring it back to the correct position. This means that human operators need to continuously monitor the coil winding process visually.

To address this issue, we have created an AI model that combines convolutional neural networks (CNNs) for extracting features from wire images and recurrent neural networks (RNNs) for detecting temporal changes in image features. This AI model detects winding disengagement from video captured by a camera installed near the processing point. Our evaluation using a pre-recorded video confirmed its ability to detect winding disengagement, achieving a practical detection rate of 97.1%.

Our next step is to implement the new AI technology into coil winding machines for verification, aiming to achieve practical application for mass production.

1.33 Enterprise Knowledge Retrieval System Augmented with Knowledge Graphs



Searches for related documents using knowledge graphs automatically generated from document set

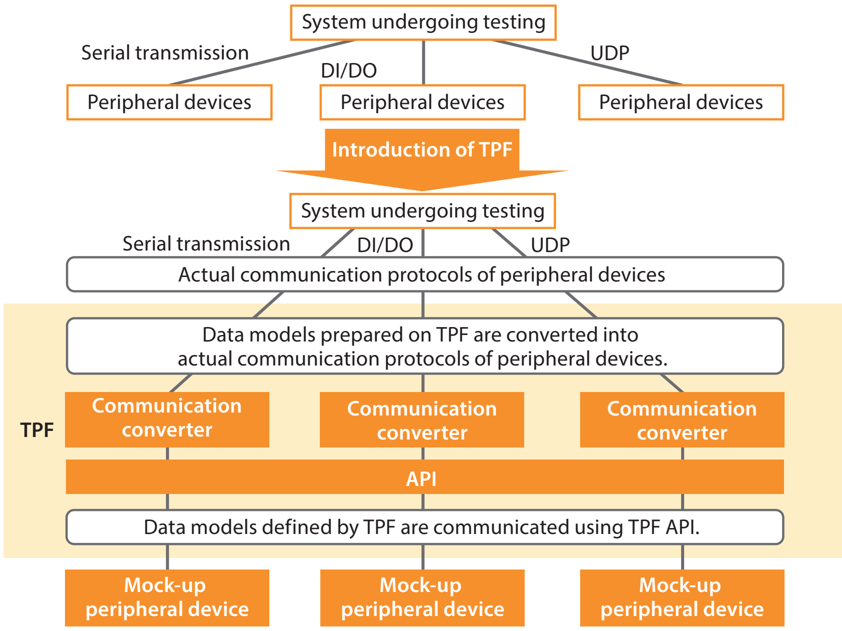
Enterprise knowledge retrieval systems, which are designed to manage and extract specific knowledge from business documents, are valuable for streamlining business operations. However, unless the user specifies appropriate keywords, the knowledge retrieval process may not provide the desired results, and significant time can be wasted in repeating a full-text search.

To solve this problem, Toshiba Corporation has developed a knowledge retrieval system augmented with knowledge graphs. It extracts representative words from stored documents and uses interlinked relationships to generate a knowledge graph. When a user performs a full-text search, the new knowledge retrieval system returns representative words associated with a set of documents in a knowledge graph. Next, the user can select specific words to expand the search range to include new documents or narrow down the search range by adding multiple representative words.

The new knowledge retrieval system enables users to discover documents that would be otherwise inaccessible with initial keywords. This eliminates the need to repeat a full-text search, and makes the process more efficient and less time-consuming.

We verified the new knowledge retrieval system using a set of documents describing cases of quality failure. This confirmed that it suggests recommended keywords accurately and facilitates extracting relevant documents that would not be found only with a full-text search.

1.34 Test Platform to Enhance Efficiency of CPS and IoT Tests via Cloud Lifting



DI/DO: digital input/output
UDP: User Datagram Protocol
TPF: test platform

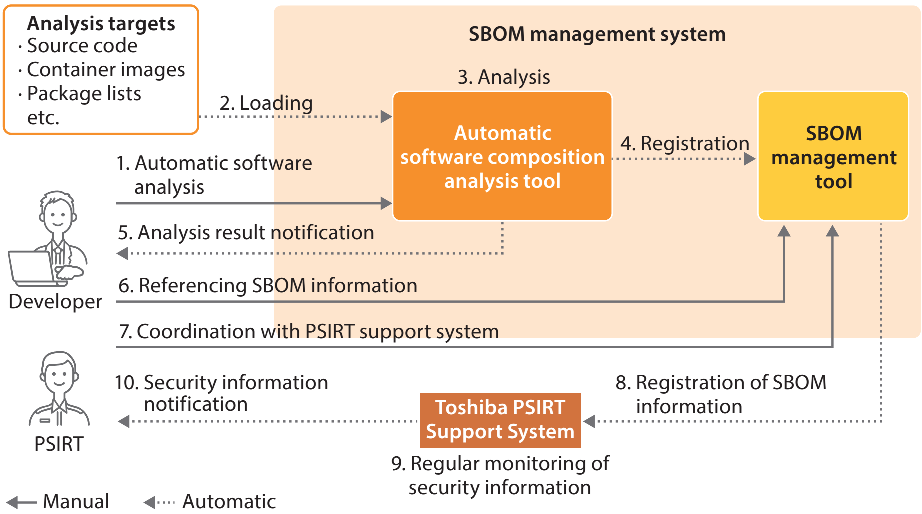
Communication system provided by test platform

Cyber-physical and Internet-of-Things (IoT) systems, which consist of many devices, require not only the constituent but also peripheral devices for system testing. This tends to increase the cost for building a test environment. Considerable development costs are incurred even when a simulator is used to mimic the behavior of peripheral devices.

To resolve this issue, Toshiba Corporation has developed a test platform that facilitates the development of mock-ups to simulate the behavior of peripheral devices on a cloud system. This test platform provides generic data models and a communication API so that cyber-physical and IoT systems can be developed without being concerned about specific communication protocols between a system undergoing testing and peripheral devices.

We have applied the new test platform to a social infrastructure system on a trial basis and confirmed that it helps to minimize system testing costs.

1.35 SBOM Management System for Efficient OSS Management



Steps 1 to 6: Automatic analysis flow
Steps 7 to 10: Flow of communication and coordination with Toshiba PSIRT Support System

Process of automatic analysis of SBOMs using SBOM management system

In recent years, software supply chains have been exposed to increasing risks related to software license violations and security vulnerabilities, and software bills of materials (SBOMs) are attracting attention as a countermeasure.

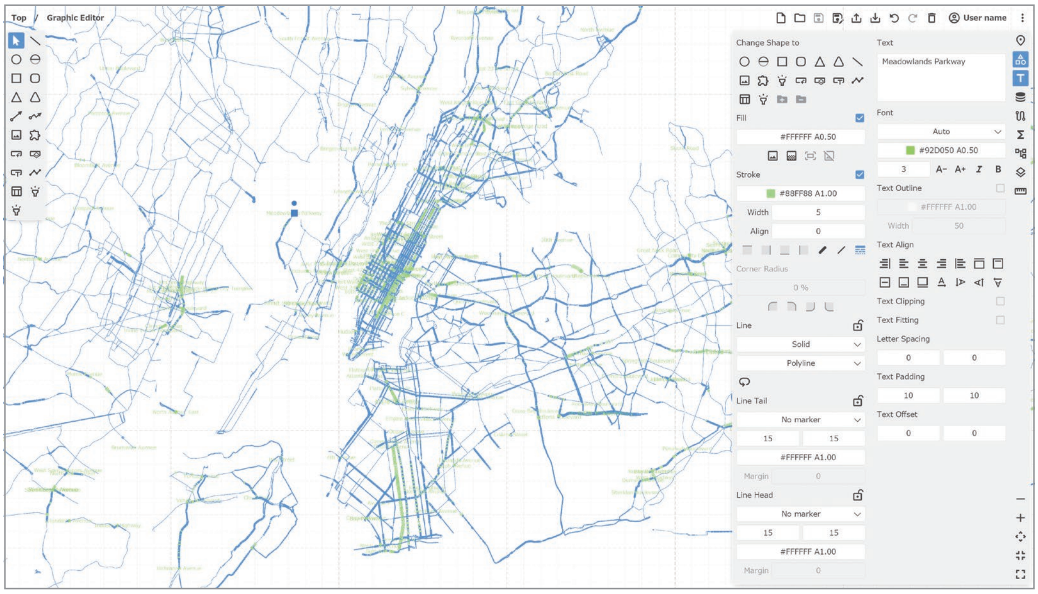
Typically, development of software products involves the integration of multiple open-source software (OSS) components, each of which may depend on several other software elements. However, because of the enormous number of software calls (fan-out), it is difficult to identify them properly and create SBOMs.

To address this issue, Toshiba Corporation has developed an SBOM management system which automatically analyzes the OSS composition of specified software resources such as source code repositories and manages the results of a composition analysis. Trial use of the new SBOM management system has resulted in 82% less time required for generating and managing SBOMs. Furthermore, our collaboration with the Toshiba Product Security Incident Response Team (PSIRT) allows us to continuously monitor for security risks present in our software products.

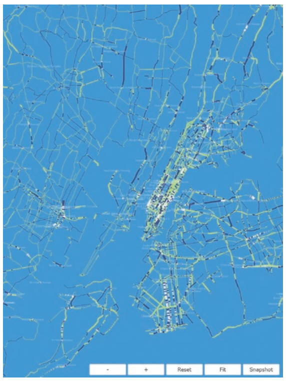
We will continue efforts to achieve practical application of the new SBOM management system. In addition to improving SBOM management efficiency, we aim to reduce the risk of license violations and enhance software security.

1. Research and Development

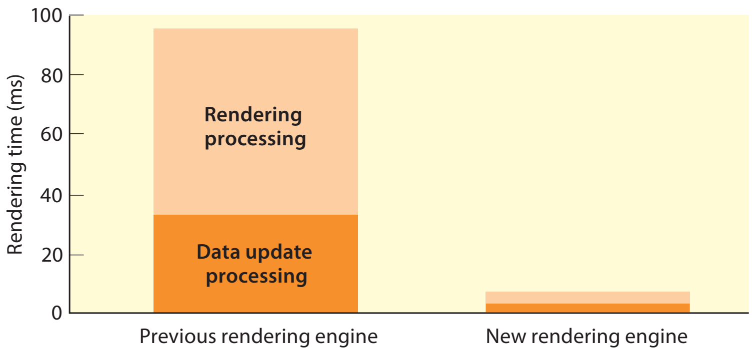
1.36 Development of Authoring Tool to Facilitate Equipment Changes and Rendering Engine for Large Diagram Datasets from SCADA Systems



Example road network diagram with 16 338 lines



Display on terminal



Example of editing highway network using new authoring tool and rendering engine, and performance measurement using tablet

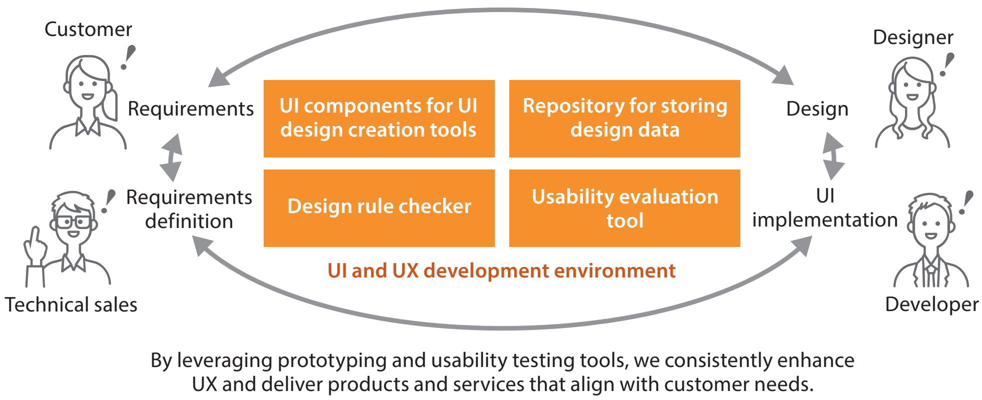
Supervisory control and data acquisition (SCADA) systems used for factory and infrastructure equipment operation and maintenance require modifications to the drawings of monitored targets such as system and process flow diagrams when any equipment is replaced or work processes change. Because these diagrams represent the dynamic states of the monitored targets, an understanding of the related technologies is essential to make even minor modifications, necessitating the assistance of system manufacturers.

To enable users of the monitored targets to easily modify their diagrams, Toshiba Corporation has developed an authoring tool that can be integrated into SCADA systems. Because this authoring tool runs on the web, it can be operated from various devices, including tablets. We have also developed a rendering engine that employs WebGL™ (Web Graphics Library), an API for rendering graphics on the web, making it possible to handle large diagrams.

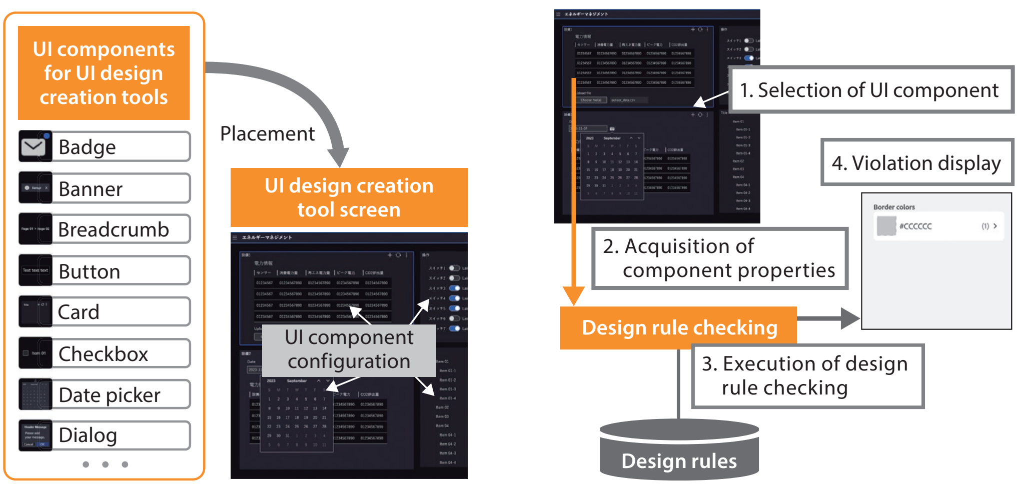
We are currently developing SCADA systems that integrate the new authoring tool and rendering engine and will work to continually improve user experiences based on their feedback.

1. Research and Development

1.37 UI and UX Development Environment Promoting Development of Intuitive UI for End Users



Agile development style useful for UI and UX development



Tool example: UI components for design tools **Tool example: Design rule checker**

The key to agile development is to respond swiftly to user needs and changes in product specifications while collaborating with customers. To do so, it is crucial to efficiently incorporate feedback from stakeholders into each step of product development. With this in mind, Toshiba Corporation has established a user interface (UI) and user experience (UX) development environment that enables UI design while facilitating information sharing among stakeholders.

It includes a set of UI components for UI design creation tools, a repository for storing and sharing design data, a design rule checker, and a usability evaluation tool for UI design. These tools allow developers to create and modify UI designs rapidly using UI components, share and discuss design specifications quickly, identify design rule violations easily, and evaluate the usability of system UI from the early design stages. Ultimately, this approach helps minimize the need for backtracking during the development cycle.