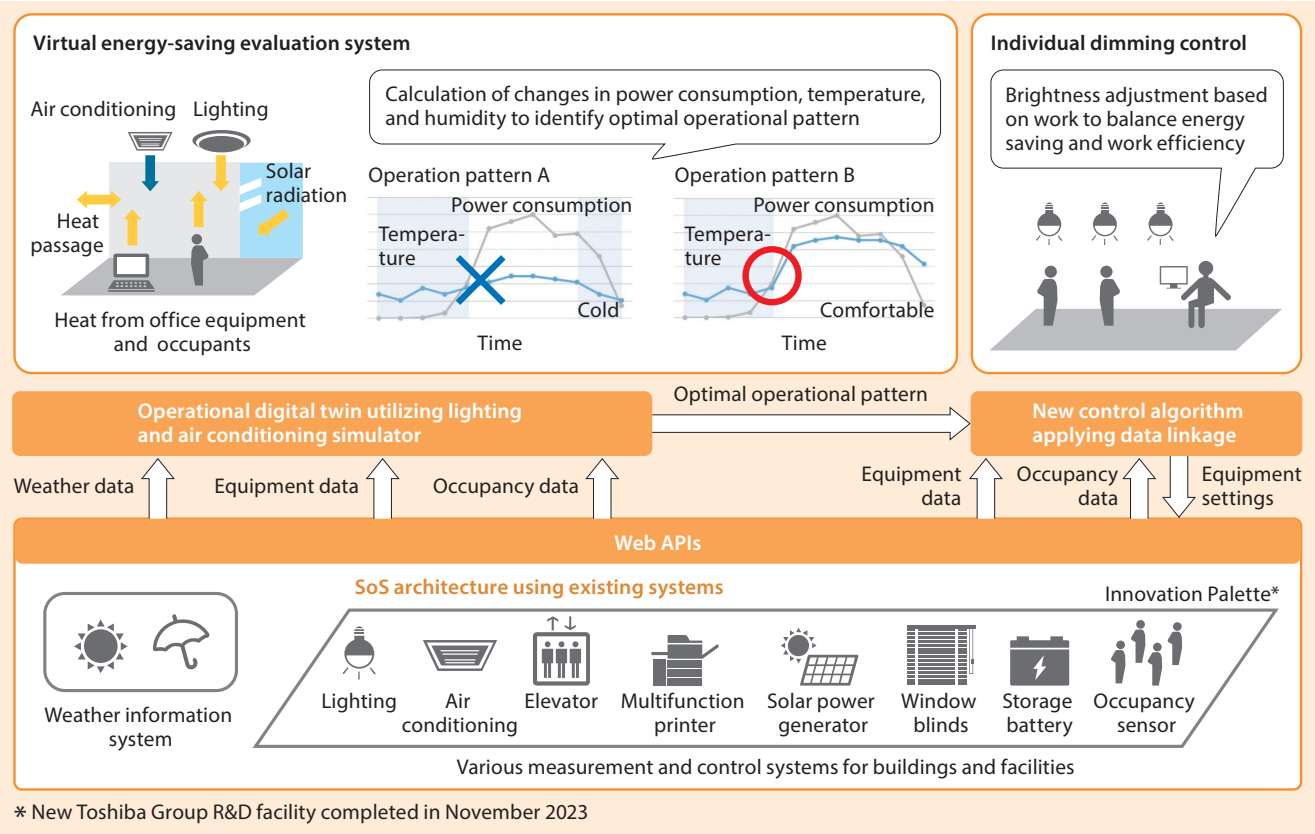
1. Research and Development

1.1 Operational Digital Twin for Energy Saving in Buildings and Facilities



Digital twin for building equipment operation utilizing AI and simulation technologies

To achieve carbon neutrality in buildings and facilities, the operation of air conditioning, lighting, and other systems must be optimized. Improving operational efficiency helps reduce the total energy consumption of buildings and facilities without compromising occupant comfort.

With this in mind, the Toshiba Group has developed an operational digital twin based on a system-of-systems (SoS) architecture, which is designed to correlate data from multiple systems to reduce overall energy consumption using artificial intelligence (AI) and simulation technologies. Leveraging this SoS platform, we are verifying the energy-saving effects of new algorithms to control data linkage.

An operational digital twin is a virtual representation of a physical object designed to simulate its behavior in real time. The new operational digital twin aggregates a variety of data, including equipment, occupancy, and weather information to simulate building equipment behavior and environmental conditions.

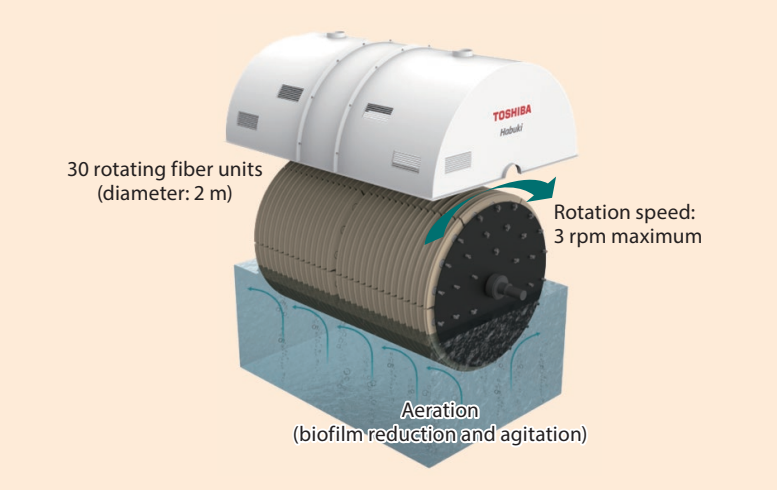
The conventional method, which manages data from different sources separately, requires on-site trial and error to adjust the balance between energy consumption and comfort, making it difficult to facilitate efficient operations. To solve this issue, the new operational digital twin

evaluates various operational patterns to identify optimal energy-saving settings. As a result, it helps improve energy efficiency while maintaining a comfortable indoor environment.

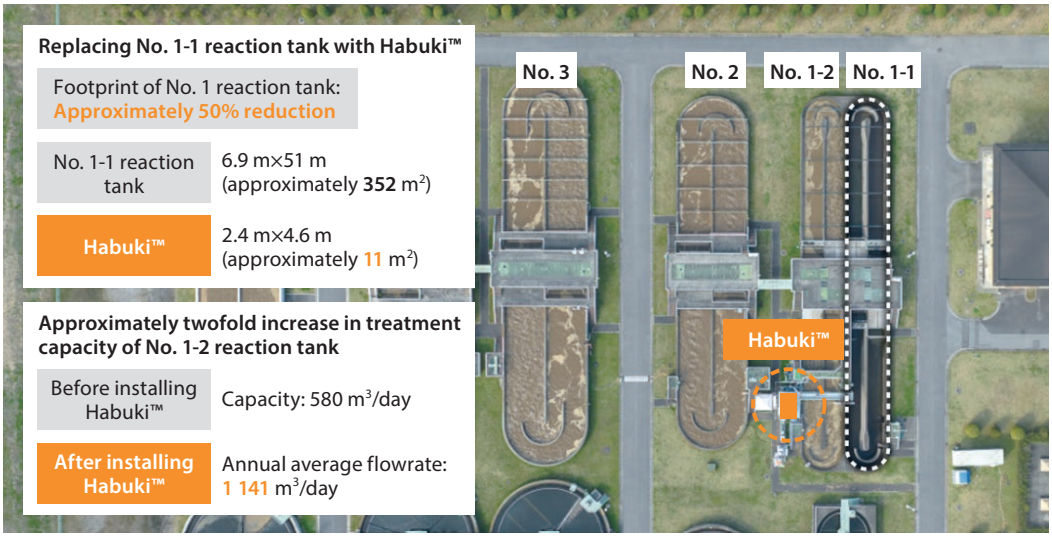
We have also implemented data linkage via web application programming interfaces (APIs) to facilitate seamless system coordination. The web APIs make it possible to share various data from multiple sources in real time, including occupancy sensors, lighting controllers, and air conditioning systems, enabling more dynamic and adaptive energy management. For example, data from occupancy sensors allow control of individual light dimmers and air conditioners to adjust the brightness and temperature in different zones according to occupancy. This provides significant energy savings without compromising comfort.

We will continue to develop practical operational platforms, provide solutions tailored to market needs, and contribute to sustainable energy management.

1.2 Habuki™ Pretreatment Unit for Small-Scale Sewerage Treatment Plants



Habuki™ pretreatment system using rotating fiber unit for oxidation ditch



Full-scale demonstration test at Ujiie Sewage Treatment Plant in Sakura City, Tochigi Prefecture

Sewerage treatment plants are facing several issues, including the need to scale according to wide-area collaboration, save energy to promote carbon neutrality, and address aging infrastructure. To solve these issues, Toshiba Corporation launched Habuki™ in July 2024.

Habuki™ is a novel sewerage treatment system with a rotating biological contactor, which is suitable as a pretreatment unit for small-scale sewerage treatment plants employing the oxidation ditch (OD) process. There are approximately 1 000 such sewerage treatment plants in Japan. Habuki™ removes roughly 50% of organic matter from water to considerably reduce the influent pollution load on reaction tanks. This helps increase the treatment capacity and reduce power consumption required for aeration at existing plants.

Habuki™ is also effective for aging infrastructure. Although renovating or repairing reaction tanks often temporarily reduces treatment capacity, employing Habuki™ as a temporary measure mitigates this issue.

The name Habuki™ was derived from the Japanese verb “habuku” meaning “save” because it contributes to saving costs, space, and complexity.

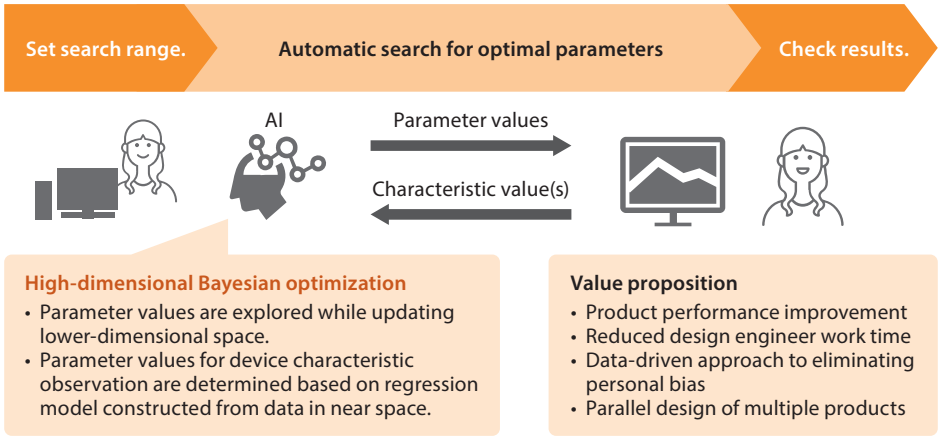
(1) Cost-saving: Habuki™ features high energy efficiency with a treatment capacity of up to 1 350 m³/day per unit and a power requirement of only 1.5 kW. Because of a hydraulic retention time of approximately 15 minutes, Habuki™ reduces the aeration power consumption of existing OD reaction tanks by 20 to 40% and decreases excess sludge generation by 10 to 20%.

(2) Space-saving: The rotating fiber body provides a microbial concentration approximately 10 times higher than OD reaction tanks, enabling efficient treatment of high pollution loads in a compact unit. This reduces the number of reaction tanks needed by the conventional OD method.

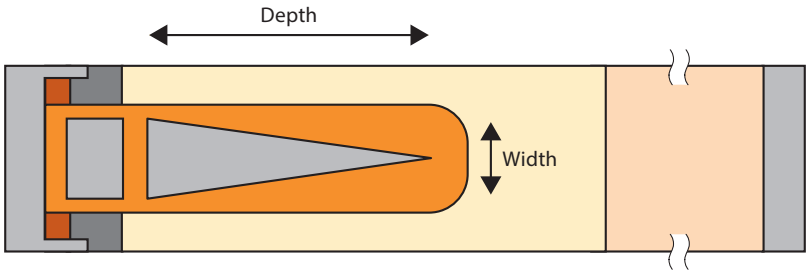
(3) Complexity-saving: Maintenance is minimal, requiring only bearing lubrication and gear oil changes in the reducer. The rotating fiber body has a lifespan of more than 10 years, and inspection is straightforward. Replacing existing OD reaction tanks with Habuki™ eliminates the need for extensive mechanical maintenance required by the conventional OD method.

Prior to the launch of Habuki™, we conducted a full-scale demonstration test at the Ujiie Water Treatment Center in Sakura City, Tochigi Prefecture, successfully confirming its performance. Habuki™ has been registered as a new technology under the JS New Tech Implementation Program of the Japan Sewage Works Agency. We will use these results to promote Habuki™.

1.3 High-Dimensional Bayesian Optimization for Automated Power Semiconductor Device Design



Design automation and high-dimensional Bayesian optimization

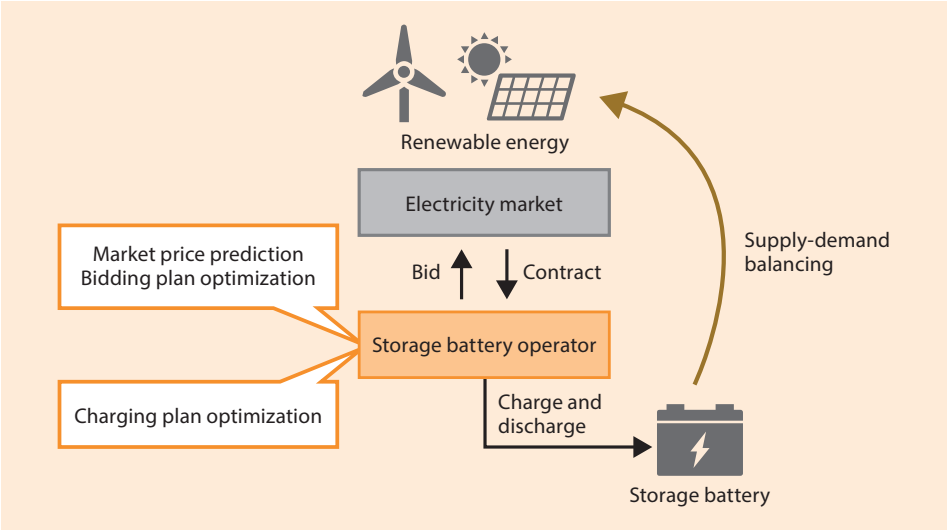


Example of design parameters for power semiconductor device

Power semiconductor devices play a prominent role in converting electric power for various social infrastructure systems. To develop power semiconductor devices, design engineers need to adjust device dimensions, donor concentration, and many other parameters. However, as the device structure becomes more complex to improve power efficiency, the number of design parameters increases, making it difficult to find parameter values that provide optimal device performance.

To address this issue, the Toshiba Group has developed a high-dimensional Bayesian optimization technique that is effective when a design requires a high-dimensional search space from which to sample design parameters. The new technique repeats the search process while setting promising lower-dimensional spaces at each point in time. It determines parameter values for observing one or more device characteristics based on a regression model constructed only from data in the vicinity of lower-dimensional spaces. Applying this technique to designing a power device consisting of six parameters, we succeeded in finding parameter values that reduced the on-resistance to two-thirds of that achieved with standard Bayesian optimization, demonstrating the feasibility of automatic power semiconductor device design.

1.4 Technology for Strategic Battery Energy Bidding on Electricity Market to Enhance Profitability



Overview of technology for strategic battery energy bidding on electricity market

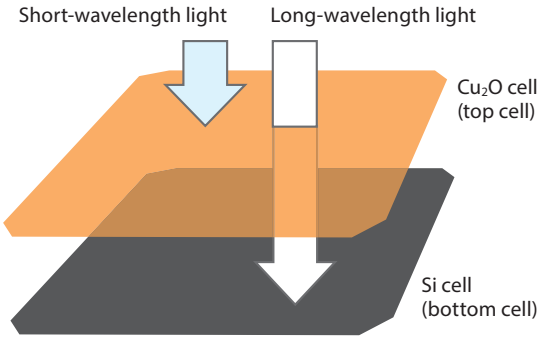
The spread of intermittent renewable energy sources is spurring the use of grid-connected storage batteries for electricity supply-demand balancing. Owners of grid-connected battery energy storage systems can earn revenue by selling battery energy on the electricity market.

To maximize revenue, it is crucial to select the right products, the right bid timing, and the right bid prices and offered quantities. However, the seller is obligated to deliver a specific quantity of battery energy to the buyer according to a contract. This means that the seller must charge their batteries to a sufficient level according to a plan.

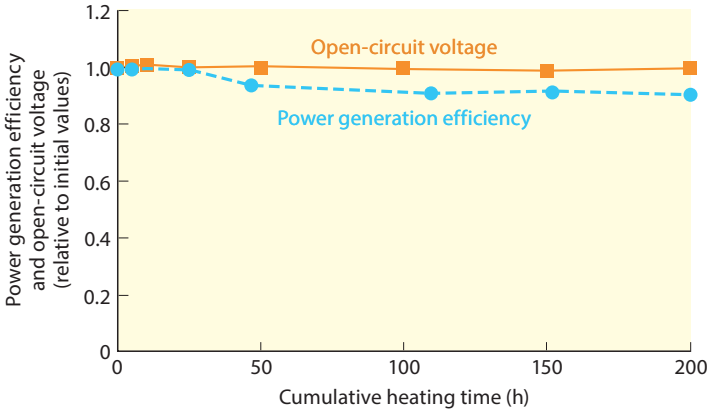
To address this need, the Toshiba Group has developed technology for strategic battery storage bidding to maximize revenue from electricity trading. It creates bidding plans automatically to secure battery charging time based on market price trend predictions. We applied this technology in Hokkaido where the electricity market price widely fluctuates and confirmed that it would provide an approximately 20% increase in seller revenue compared to a plan to bid at the average of the highest winning bids for all time zones.

We will utilize this new technology in our battery control services.

1.5 Improving Thermal Stability of High-Efficiency Tandem Solar Cells Consisting of Stacked Cu_2O and Si Cells



Cu_2O/Si tandem solar cell structure



Results of Cu_2O cell thermal stability test at 120°C

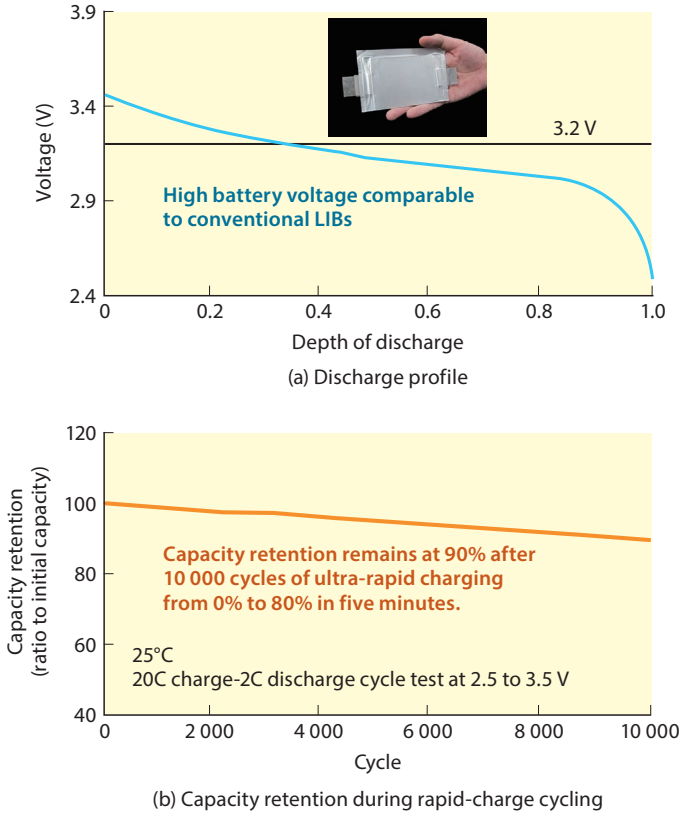
High-efficiency tandem solar cells consisting of a cuprous oxide (Cu_2O) cell stacked on a silicon (Si) solar cell are expected to contribute to achieving carbon neutrality. Using transparent Cu_2O cells developed in 2019, the Toshiba Group is developing tandem solar cells capable of supplying a large amount of power even in a limited installation space.

We tested the thermal stability of a cell (size: 40×42 mm) composed of 14 series-connected Cu_2O cells that uses a stable amorphous zinc oxide film for transparent electrodes. Exposing the cell to 120°C for 200 hours confirmed its open-circuit voltage stability, a requirement for automotive applications. Furthermore, there was no significant degradation in the internal pn junction, which is crucial for power generation.

Although power generation efficiency deteriorated gradually, the cause is likely a decrease in electrical conductivity triggered by the reaction of the transparent electrode surface with atmospheric components. We aim to improve this by enhancing tandem solar cell sealing. Moving forward, we will further enhance our thermal stability improvement technologies with the aim of demonstrating Cu_2O/Si tandem solar cells capable of powering electric vehicles without charging around 2028.

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

1.6 Rapidly Chargeable 3 V-Class Battery with Cobalt-Free Cathode and Oxide-Based Anode



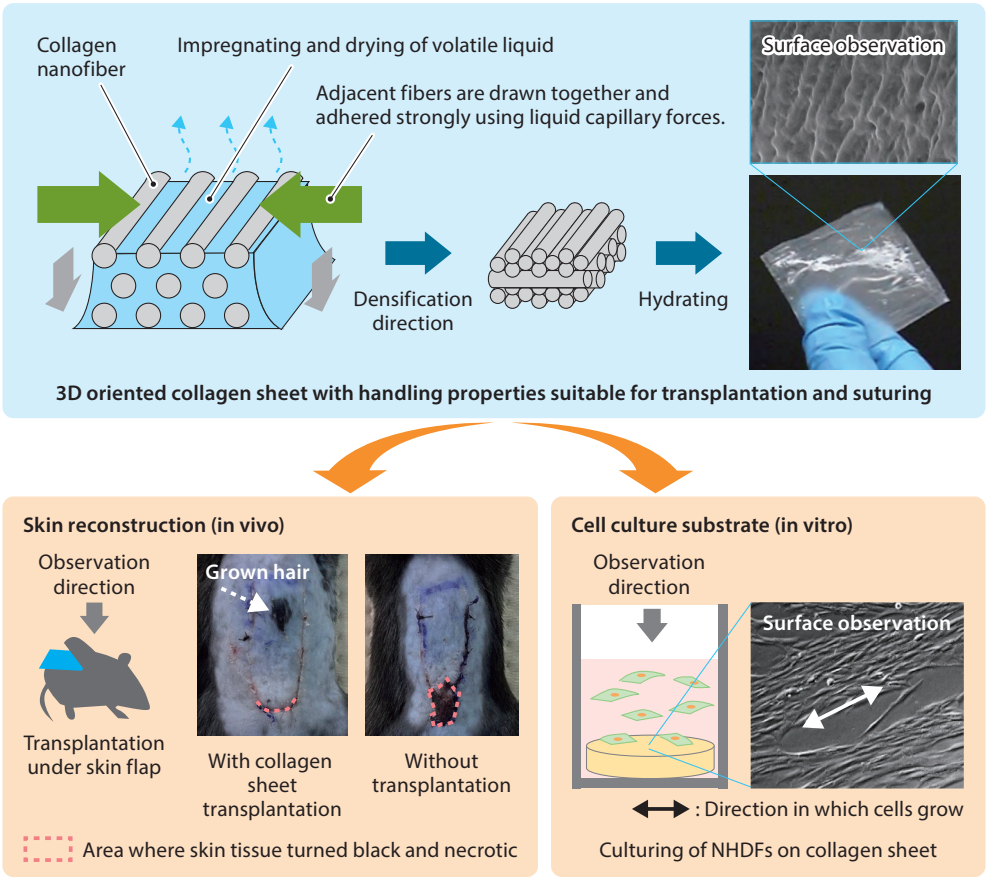
(a) New 3 V-class oxide-anode battery and (b) Capacity retention during rapid-charge cycling

The Toshiba Group has developed a rapidly rechargeable 3 V-class battery with a cobalt-free cathode and an oxide-based anode. Batteries with an oxide-based anode are well-known for their excellent safety and long life, allowing rapid charging. However, their applications are restricted because of low working voltage.

To address this issue, we explored the possibility of lithium nickel manganese oxide (LNMO) as a cathode material because it can be charged to a high voltage of 5 V and is free of environmentally damaging cobalt. However, the gases generated from the LNMO cathode during charging cause problems such as battery swelling.

To reduce gas generation, we improved the battery components to suppress the dissolution of transition metals from the cathode. We confirmed that a battery combining an LNMO cathode and niobium titanium oxide (NTO) anode generates only 1/1 000th as much gases as conventional lithium-ion batteries (LIBs). Additionally, the new battery achieved a 3.2 V output voltage, 80% charging from 0% in five minutes, and a 90% capacity retention after 10 000 cycles without battery swelling. This battery has wide-ranging applications, including compact industrial applications requiring high voltage and high performance.

1.7 Medical Collagen Sheet Manufactured Using Nanofiber Technology



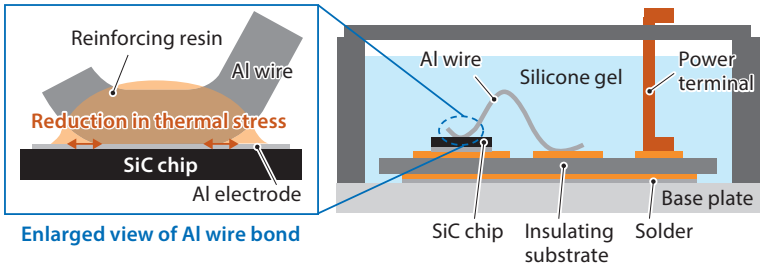
3D oriented collagen sheets manufactured using unique nanofiber adhesion method

Using electrospinning nanofiber technology, the Toshiba Group is developing a three-dimensional (3D) oriented collagen sheet that mimics biological tissue, aiming for applications in skin reconstruction and cell culture. To date, we have applied our unique nanofiber adhesion process using liquid capillary forces to create a high-elasticity 3D collagen sheet with handling properties suitable for transplantation and suturing even when it contains water. Additionally, when transplanted under a skin flap, the collagen sheet integrated with the surrounding tissue and disappeared, indicating a good skin grafting outcome.

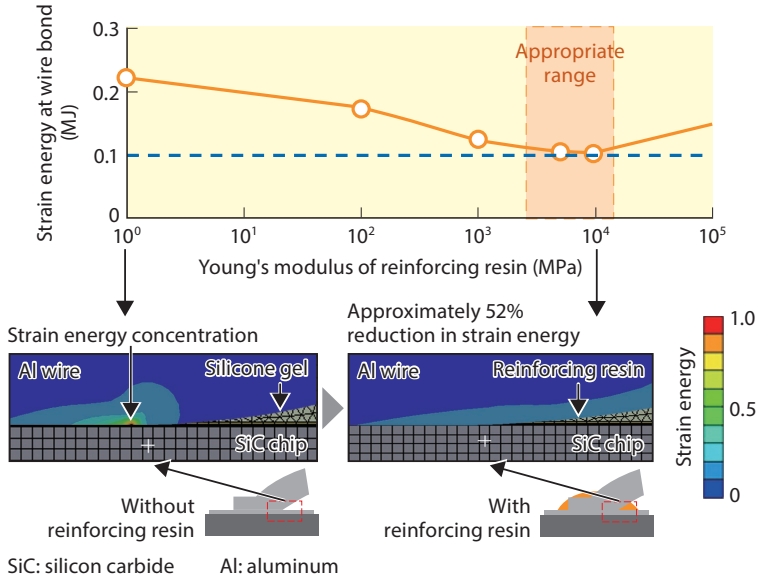
We investigated the inflammatory response to the collagen sheet using macrophages and found that it does not cause significant secretion of inflammatory cytokines, indicating its low inflammatory property. Because it is highly biocompatible, we also demonstrated its potential applications for tissue regeneration. Furthermore, when applying the new collagen sheet to culture experiments using normal human dermal fibroblasts (NHDFs), we found that the growth direction of cells on the sheet surface was controlled.

We will collaborate with both internal and external stakeholders to advance functional verification and achieve practical application of this new technology.

1.8 Wire Bond Reinforcement Technology Using Resin to Enhance Reliability of Power Semiconductor Modules



Wire bond reinforcement technology using resin



Effect of reinforcing resin properties on strain energy

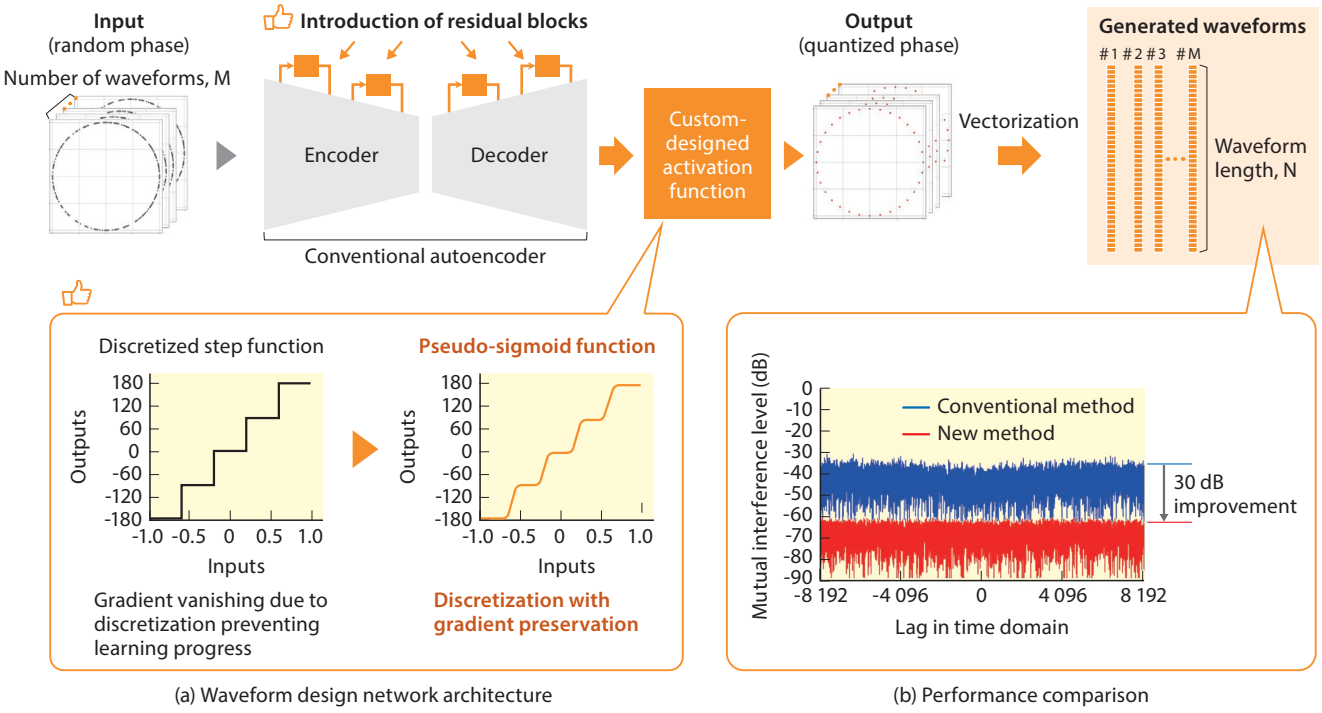
To achieve a carbon-neutral society, the application of power semiconductor modules to electric power control in trains, electric vehicles, and solar power generation devices is moving forward. The Toshiba Group has developed a wire bond reinforcement technology using resin, as wire bonds are prone to failure in power semiconductor modules. This technology improves wire bond durability against thermal stress due to repeated module energization.

Two characteristics are required for the reinforcing resin: the ability to relieve stress applied to wire bonds, and high adhesion to maintain that ability. We determined the optimal Young's modulus range for the reinforcing resin via finite-element structural analysis. We also controlled the heating process for the resin to improve adhesion considering its physical properties.

We confirmed that the resin more than triples wire bond durability against thermal stress and reduces strain energy by approximately 52%.

We will commercialize and expand the lineup of highly reliable power semiconductor modules to contribute to reducing the power consumption of electrical equipment.

1.9 Waveform Design Technology Using Deep Learning to Improve Frequency Utilization Efficiency



Overview of waveform design technology based on deep learning

In the face of increasingly scarce radio spectrum resources, efficient use of limited frequency bands has become a pressing issue. Enhancing spectrum utilization efficiency directly contributes to increasing the capacity of communication systems and improving the detection accuracy of radar systems. Therefore, this is a crucial social, economic, and security issue.

One effective approach to improving frequency utilization lies in the design of waveforms to enable multiple devices in a given system to transmit radio signals simultaneously with minimal mutual interference. However, conventional algebraic design methods face inherent limitations: they constrain the number and length of usable waveforms and suffer performance degradation due to discretization effects during practical implementation, limiting their scalability and real-world applicability.

With this in mind, leveraging deep learning, the Toshiba Group has developed a novel waveform design technology which allows for flexible adaptation to arbitrary waveform lengths and quantities. The technology is based on reinforcement learning enhanced by autoencoders—a class of deep learning models—enabling the generation of waveforms that meet strict mutual interference constraints with high flexibility.

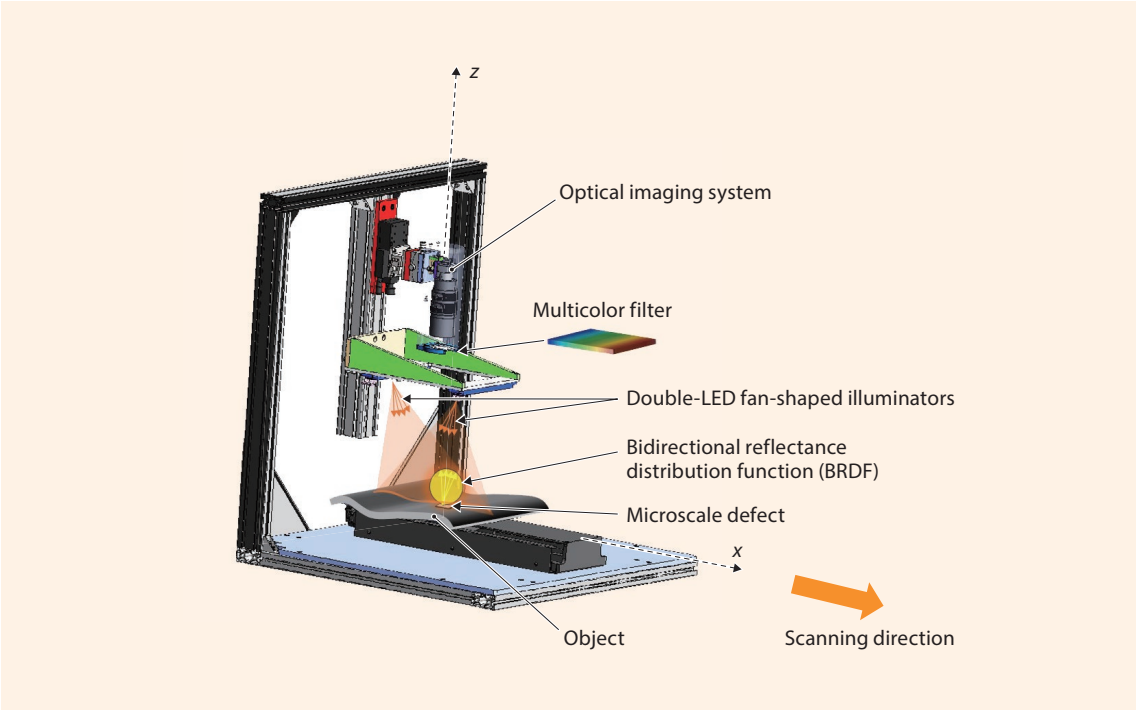
A key challenge in applying deep learning to waveform design is the gradient vanishing problem caused by discretization effects, which can stall the learning process. To overcome this problem, we integrated residual blocks, and a custom-designed activation function tailored

for the waveform design domain, ensuring stable and effective learning even under discrete implementation conditions.

Experimental validation using actual hardware demonstrated that the new method reduces mutual interference by approximately 30 dB compared to conventional methods, confirming its practical feasibility.

The new technology shows significant promise for the defense sector as it supports efficient frequency sharing across multiple operational systems. It also enhances low-probability-of-intercept (LPI) performance and improves range and resolution in surveillance and search operations. Looking ahead, we aim to deploy this technology in radar systems for defense applications, with a view to expanding into commercial applications through industry-government collaboration.

1.10 Technology for Real-Time Optical Inspection of Steeply Inclined Product Surfaces



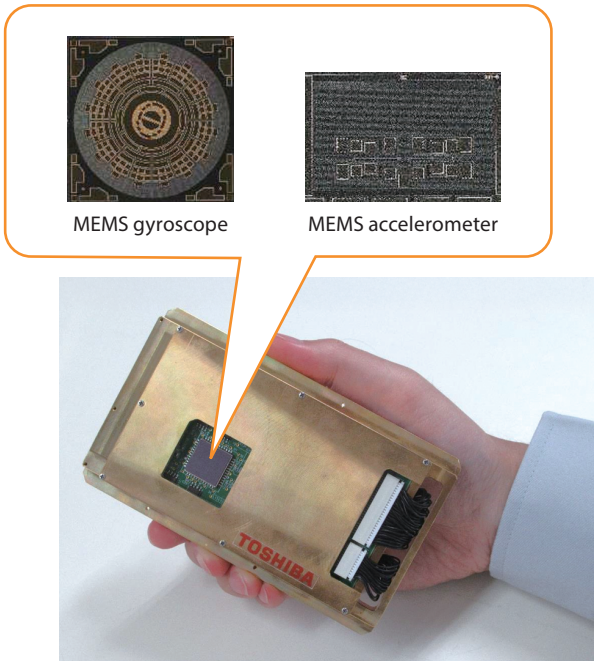
Schematic view of dual fan beam emitting optical imaging system

Various manufacturing lines, including those for automobiles and semiconductor devices, require high-speed, real-time, non-contact inspection of product surfaces to detect minute defects, replace manual visual inspections, and ensure quality control for all products. However, many conventional imaging techniques do not provide sufficient contrast for microscale surface defects—especially for those with microscale height variations—resulting in blurred images and missed defects.

To address this issue, the Toshiba Group developed a novel imaging technique known as one-shot bidirectional reflectance distribution function (BRDF) imaging, which captures the BRDF of such defects as color variations, enabling instant image enhancement and visualization. Nevertheless, detecting defects on curved surfaces poses a challenge because the light reflected from curved surfaces often does not return to the imaging system. Therefore, we designed an optical system that combines a single light-emitting diode (LED) light bar source capable of emitting fan-shaped rays and a multicolor filter that captures the angular distribution of reflected light as color information. This system allows instantaneous acquisition of directional reflectance distributions from each point on a curved surface. However, with only a single LED light bar source, the incident angle of fan-shaped illumination on an object is limited, making it difficult to image reflected rays with large angles of reflection. This restricts application of the system to inspection of surfaces with inclination angles of less than ±10°.

To solve this issue, we redesigned the optical system, placing two LED light bar sources outside the imaging field of view. This configuration provides fan-shaped illumination with large incident angles at every point within the imaging area. The new system can now capture reflected light from surfaces with up to ±20° to ±30° inclinations, making it possible to observe microscale defects with height differences of less than a few micrometers as color changes. This advancement makes it possible to perform real-time inspection of objects with steeply inclined surfaces directly on production lines, even while products are being transported.

1.11 Compact, High-Precision Inertial Sensor Module and Portable Gyrocompass



Compact, high-precision inertial sensor module

Portable gyrocompass

Inertial measurement units (IMUs) measure the position of objects using the output of inertial sensors such as gyroscopes and accelerometers. IMUs are valuable for navigation in environments where global positioning system (GPS) signals or radio waves are unavailable as well as in environments with poor lighting where camera-based navigation systems do not work, such as tunnels and dark indoor spaces. IMUs are therefore attracting attention as environmentally robust positioning devices.

As autonomous mobility advances, the applications of IMUs are expected to expand from the aerospace and defense sectors to automated guided vehicles (AGVs), drones, railways, and autonomous vehicles. The challenge lies in miniaturizing and improving the precision of an inertial sensor module, which is a key component of the IMU.

With this in mind, the Toshiba Group has developed a compact inertial sensor module using our proprietary microelectromechanical system (MEMS) technologies. The new inertial sensor module incorporates a gyroscope with a world-class bias instability(*1) of less than 0.01°/h(*2) and an accelerometer with a world-class bias instability of less than 1 μG (9.8 μm/s²)(*2). An IMU with this inertial sensor module meets the navigation-grade performance required for trans-Pacific flights without GPS support.

Additionally, Toshiba Electro-Wave Products Co., Ltd. has developed a portable gyrocompass using the new inertia sensor module, confirming that it can estimate the true north direction with an azimuth accuracy of 0.056°. Unlike typical compasses using the Earth's magnetic field, the gyrocompass measures the azimuth based on the Earth's rotational angular velocity

without being affected by magnetic disturbances or shields. An azimuth accuracy of 0.056° suffices even for defense applications to determine the installation direction of radars and other equipment. The new gyrocompass is also expected to be applicable in a wide range of fields such as civil engineering surveys and underground drilling.

Part of this work was funded by the Acquisition, Technology & Logistics Agency (ATLA) of the Ministry of Defense of Japan under the Innovative Science and Technology Initiative for Security, Grant Number JPJ004596.

(∗1) An index of sensor output stability. The smaller the value, the higher the accuracy.

(∗2) As of April 2025 (according to the Toshiba Group research)

1.12 Double-Transmon Coupler: Tunable Coupler to Achieve Higher-Performance Superconducting Quantum Computers

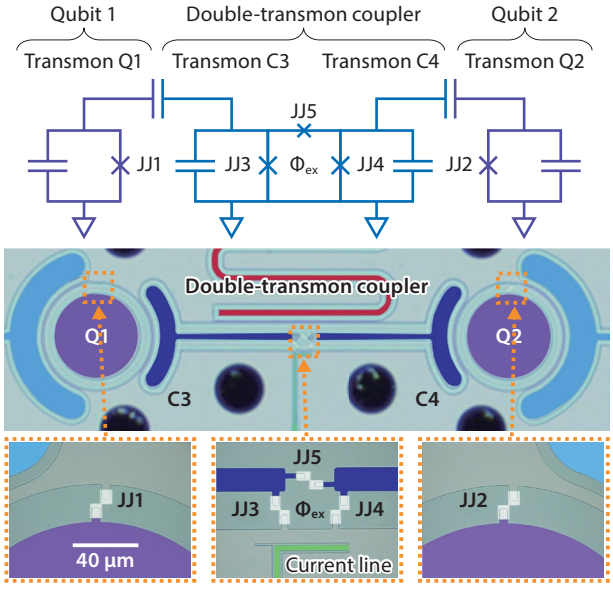
Quantum computers have attracted much attention in recent years. Although there are various approaches to quantum computer implementation, the one based on superconducting circuits is particularly promising. The key to improving the performance of superconducting quantum computers is a tunable coupler, a component that can both increase gate operation speed and suppress idle-time errors by turning the coupling between quantum bits (qubits) on and off. However, it is difficult for a conventional tunable coupler to sufficiently turn off the coupling between highly detuned qubits, which are preferable for error suppression.

In 2022, the Toshiba Group proposed a theory for a unique tunable coupler called a "double-transmon coupler" capable of turning off the coupling between highly detuned qubits. Collaborating with RIKEN, a national scientific research institute in Japan, we succeeded in achieving the world's first experimental double-transmon coupler(*1). Consequently, for two qubits with a large detuning of 464 MHz, we achieved a small coupling strength of about 6 kHz during turn-off and a large coupling strength of about 80 MHz during turn-on, resulting in a very high on/off ratio of about 13 000, as was theoretically expected. Harnessing this large coupling rate, we achieved a fast two-qubit gate with a gate time of 48 ns, leading to the world's highest-class gate fidelity(*2) of 99.90%. We aim to further improve the performance and increase the number of qubits for superconducting quantum computers.

The above results were achieved through collaboration with Yasunobu Nakamura's team at RIKEN. Part of this research was sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan's Quantum Leap Flagship Program (Q-LEAP) (Grant No. JPMXS0118068682).

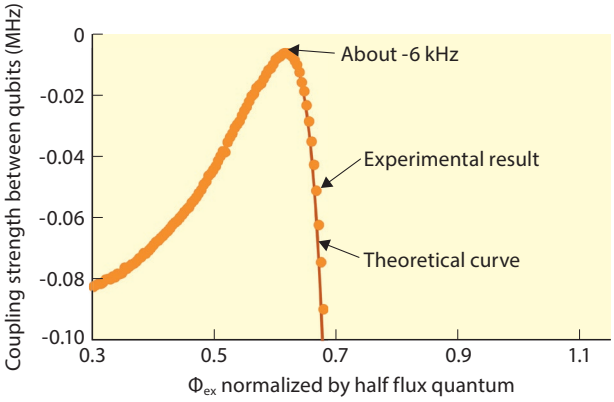
(*1) As of October 2024 (according to Toshiba Group research)

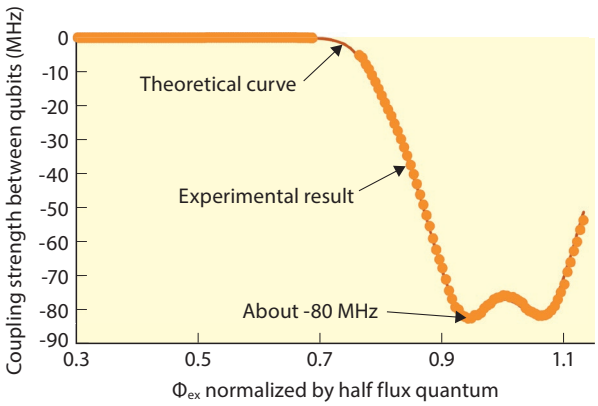
(*2) Figure of merit representing how close an actual gate operation is to the ideal one



JJ1 to JJ5: Josephson junction Φ_{ex}: external flux through loop

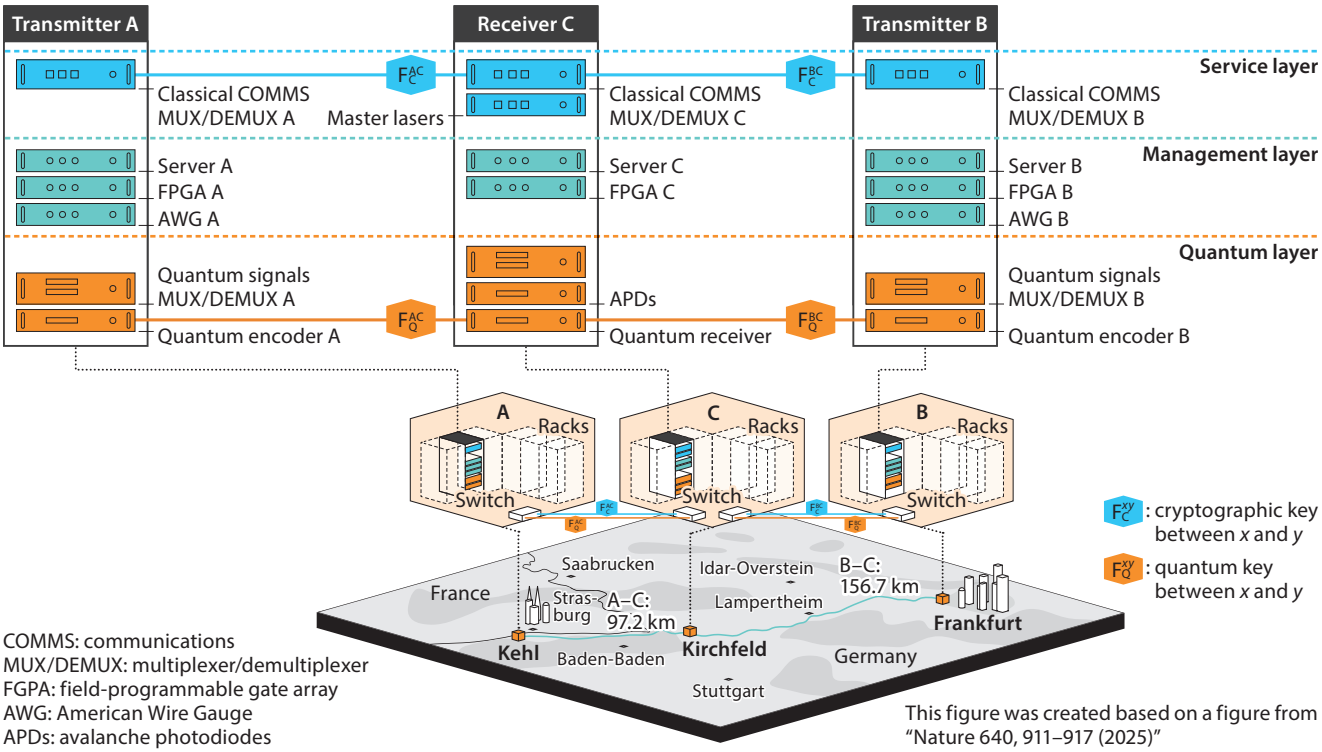
Circuit diagram and photo of double-transmon coupler (created based on a figure provided by RIKEN)





Coupling strength measurement results

1.13 Practical Long-Distance Quantum Communication within National Scale Telecom Infrastructure over 250 km of Optical Fiber



Configuration of TF-QKD demonstration system

The emergence of quantum computing threatens the conventional cryptographic techniques that we use today for secure communication. Quantum key distribution (QKD) has emerged as a provably secure solution based on the laws of nature.

Toshiba Europe Ltd. recently invented a new QKD protocol called twin-field QKD (TF-QKD) with double the maximum communication distance and demonstrated quantum communication over 600 km of optical fiber. However, practical application was difficult due to reliance on laboratory-grade equipment such as cryogenic detectors and low-vibration environments.

To solve this issue, we designed an advanced TF-QKD system using only standard equipment found in typical telecommunication data centers. We developed and deployed a portable prototype in Germany through collaboration with GÉANT(*1). Our equipment was installed in standard colocation data centers 254 km apart. The TF-QKD system included laser sources in Kehl (A) and Frankfurt (B) and an untrusted measurement center mid-way at Kirchfeld (C).

Real-world optical fiber across hundreds of kilometers under roads and buildings experiences many perturbations and noise, which can degrade quantum transmission. However, the new TF-QKD system included sensors and feedback mechanisms to compensate, achieving a secure key generation rate of 110 bits/s over 254 km. This exceeds the performance of current

commercial QKD products and represents the world's first real-world demonstration of this protocol without cryogenics(*2). Our new technology paves the way to longer-distance quantum-secure communications in real-world telecommunication infrastructure.

This project was partially funded by the European Union (EU) through the H2020 project, OpenQKD, and 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) pan-European data network for the research and education community

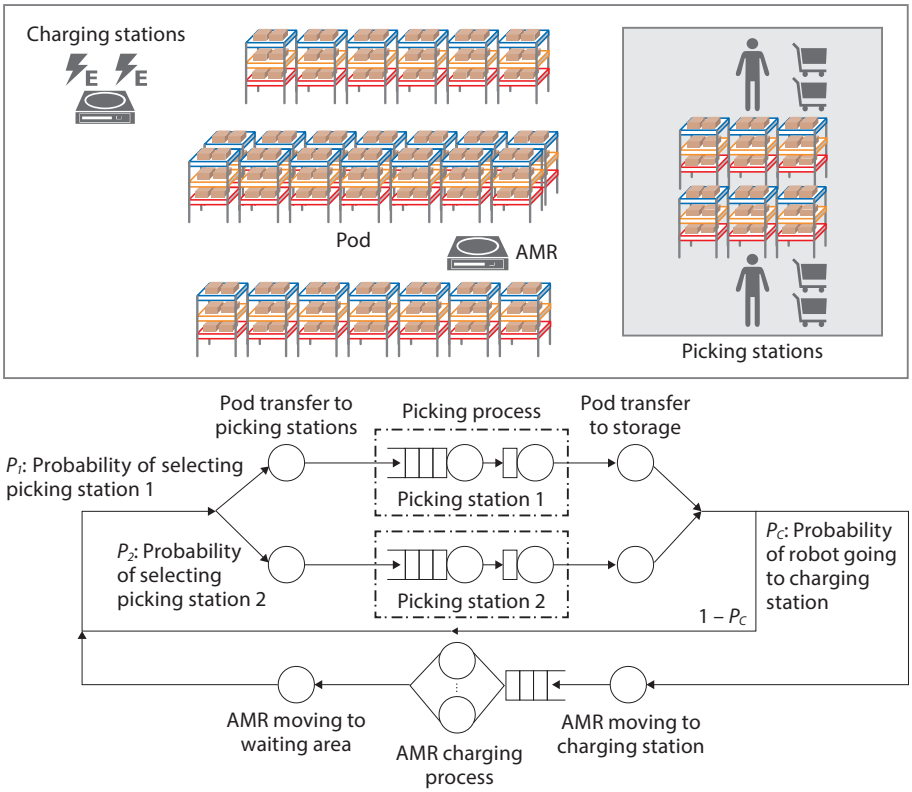
(*2) As of May 2024 (according to Toshiba Europe Ltd. Research)

1.14 Technology for Ultrahigh-Speed AMR Performance Evaluation for Logistics Automation

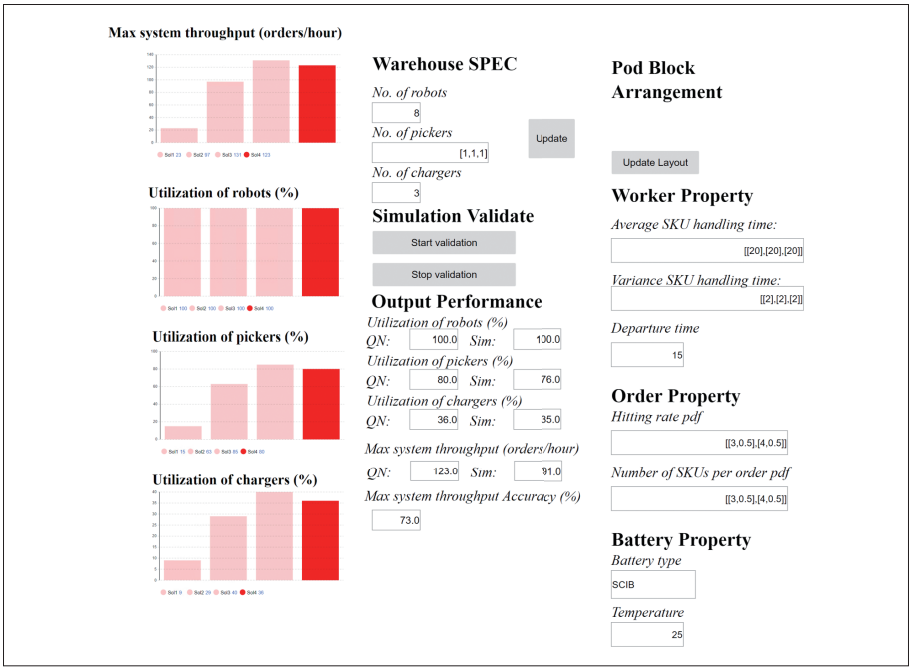
Because of expanding e-commerce and the declining population, labor shortages in the logistics industry have become severe, driving the need for warehouse automation to improve efficiency and save labor. Goods-to-person (G2P) systems using autonomous mobile robots (AMRs) to transport product pods to picking stations are attracting much attention as a possible solution. To promote adoption of G2P systems, it is important to convince potential customers of their cost-effectiveness at the proposal stage. To do so, it is essential to estimate the number of AMRs and picking stations necessary to achieve the required throughput and evaluate their performance, considering the characteristics of the batteries used. In the past, simulators were used to present the cost-effectiveness of G2P solutions to customers, but it took time to obtain stable performance results.

To solve this issue, the Toshiba Group has introduced a mathematical model based on a queuing network (QN) and developed an estimation tool that is approximately 1 000 times faster than the conventional discrete event simulator without compromising accuracy. The new tool extracts AMR travel time statistics from simulations and passes them to the QN model. This makes it possible to generate QNs automatically and thus accommodate changes to the warehouse layout. Furthermore, the QN model incorporates battery characteristics and the corresponding numerical solutions to evaluate the AMR throughput, and the number of charging stations required for different types of batteries. This has also made it possible to visualize the excellent low-temperature characteristics of our SCiB™ rechargeable lithium-ion batteries mounted on AMRs for refrigerated warehouses from an automation system perspective.

We will utilize the new tool to propose G2P automation systems to customers and quantitatively evaluate the effectiveness of SCiB™ for warehouse automation systems.

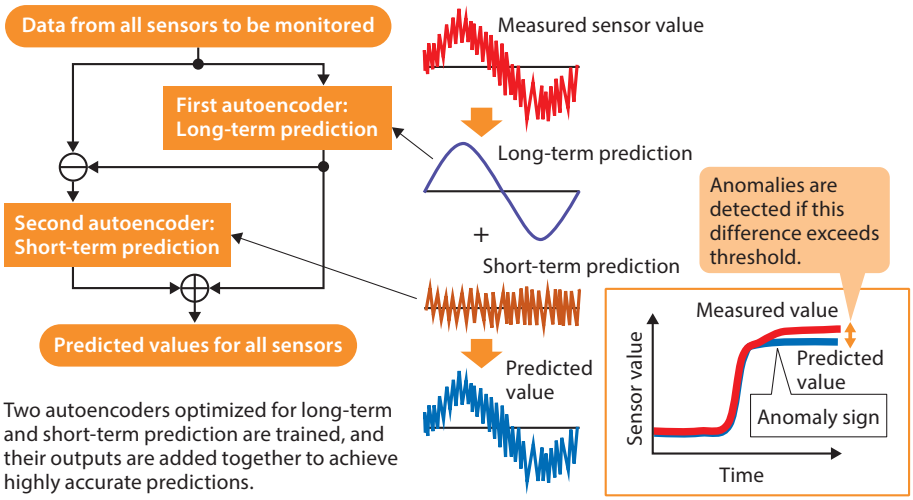


Warehouse automation using AMRs and queuing network models

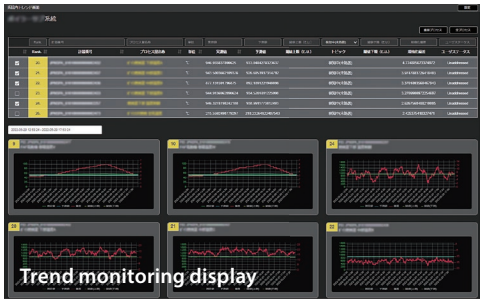


Examples of estimation tool output images

1.15 Launch of Anomaly Detection AI Capable of Early-Stage, High-Accuracy Detection of Latent Anomalies in Changing Conditions at Large-Scale Industrial Plants



Flowchart of operations in architecture of two-stage autoencoder



Example of anomaly detection system trend monitoring display

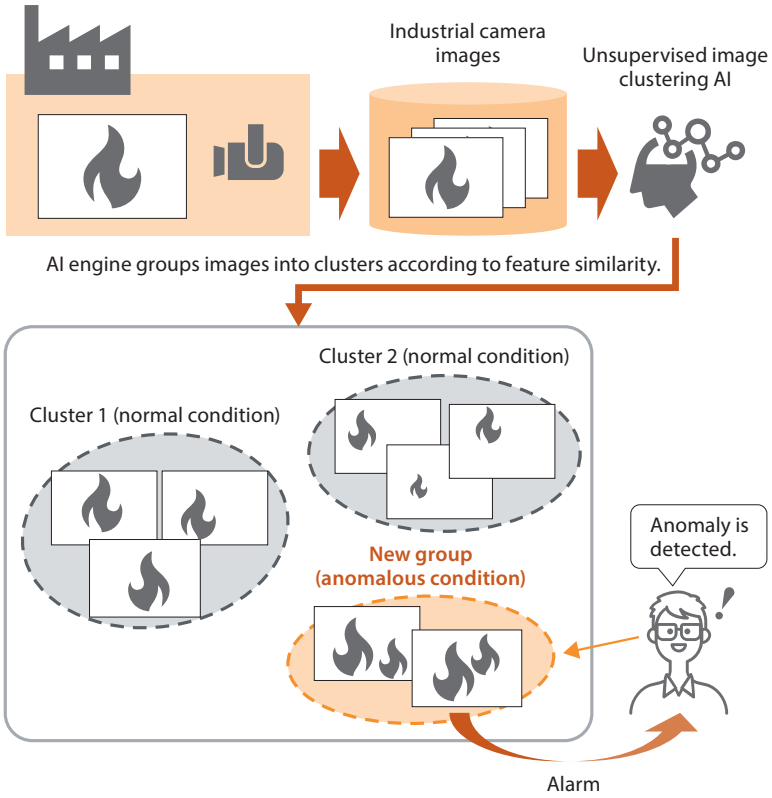
To facilitate operations and maintenance of ever more complex large-scale industrial plants, large volumes of time-series data collected from thousands of sensors installed on equipment must be monitored and then evaluated to detect anomalies at an early stage.

The Toshiba Group has developed a two-stage autoencoder anomaly detection AI capable of detecting any signs of anomalies hidden in changes in plant operating conditions at an early stage. Such a task, which has traditionally been difficult, is possible thanks to learning the complex relationships between large volumes of time-series data from various sensors. This makes it possible to conduct appropriate maintenance at an early stage according to anomaly and deterioration conditions and is expected to streamline maintenance and improve operational efficiency of large-scale industrial plants through condition-based maintenance.

A demonstration test at the Mikawa Power Plant operated by SIGMA POWER Ariake Corporation, a subsidiary of Toshiba Energy Systems & Solutions Corporation, confirmed that the latent signs of anomalies can be detected early through online monitoring of a large amount of data.

In February 2024, we launched this AI both as cloud and on-premises services as part of TOSHIBA SPINEX for Energy, a collection of digital services for electric power companies and manufacturers.

1.16 Unsupervised Image Clustering AI Technology to Automatically Group Images from Cameras at Industrial Plants and Detect Unknown Anomalies



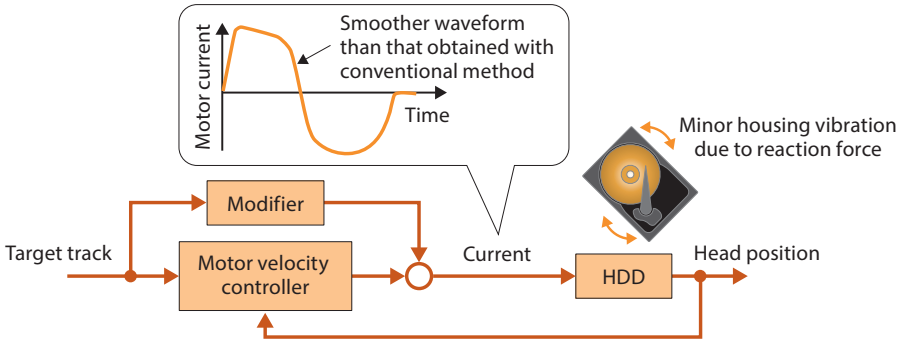
Detection of anomalies in industrial camera images using unsupervised image clustering AI

At industrial plants, human personnel visually check the images captured by cameras to monitor plant anomalies. To save labor and prevent missed anomalies, there is a need to automate the monitoring process using AI technology. It has been difficult, however, for AI to learn anomalous conditions in advance because fluid materials, furnace flames, and other objects to be monitored have irregular and varying shapes.

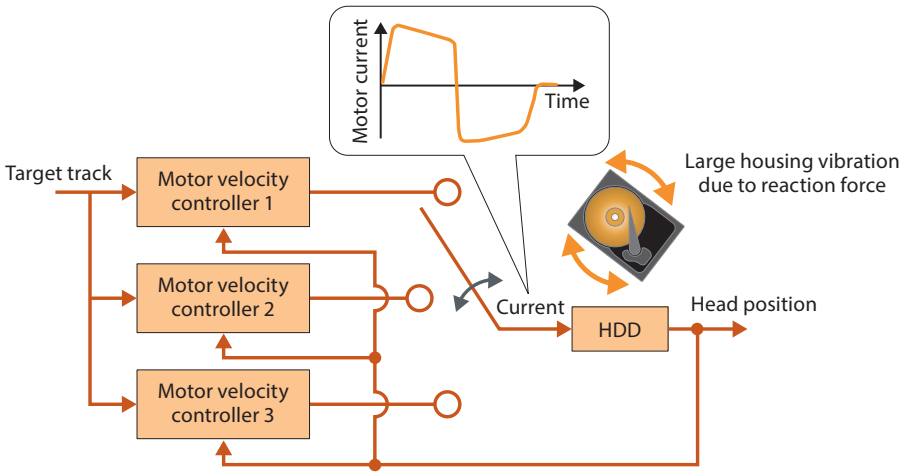
To solve this issue, the Toshiba Group has developed unsupervised image clustering AI technology to learn features in images and group them into clusters according to similarity. Leveraging this technology, we have developed an AI engine that automatically detects unknown anomalies in images. This makes it possible to identify multiple clusters of normal images and issue an alarm when a cluster that deviates from them is detected, eliminating the need for constant monitoring by human personnel. Experiments using publicly available data from road surveillance cameras have confirmed that the new AI engine can detect traffic congestion.

We have incorporated the new AI engine into an industrial plant monitoring system with the goal of releasing it to the public.

1.17 Nearline HDD Control Technology to Reduce Reaction Force during Seek



Block diagram of proposed seek control system to reduce reaction force



Block diagram of conventional seek control system

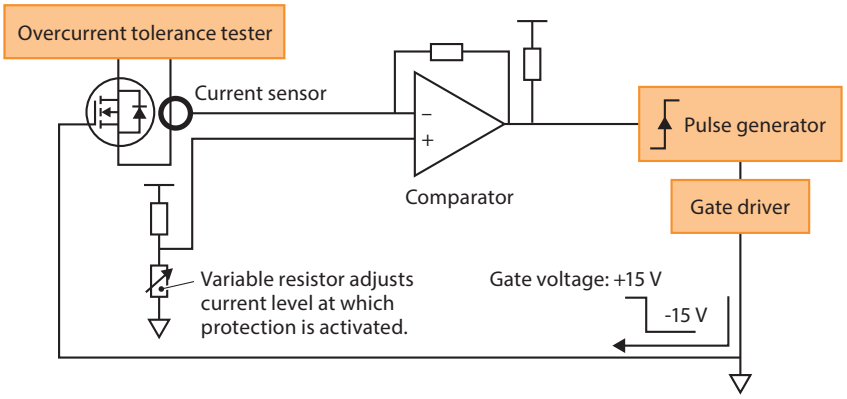
Nearline hard disk drives (HDDs) for data centers are required to provide high storage capacity and high data access performance with a small reaction force(*1) during a seek(*2). The seek controller must slow down the accelerating platters smoothly by shaping the motor current waveform. It is difficult, however, for conventional seek controllers to smooth the motor current waveform sufficiently enough to reduce the reaction force during a seek.

With this in mind, the Toshiba Group has developed a new seek control system, which moves the head to the vicinity of the target track without switching a controller. This system incorporates new technology to smooth the motor current waveform during a transition from acceleration to deceleration. The new seek control system has achieved reduced seek reaction, resulting in a 7% reduction in residual head vibration. We will use it in our next-generation nearline HDDs.

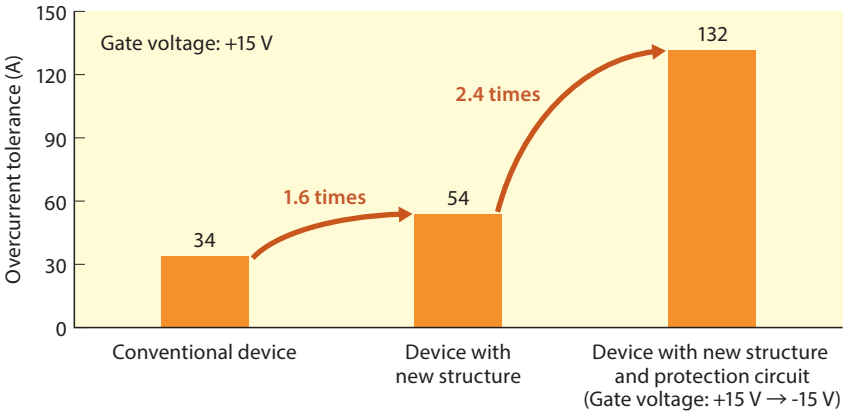
(*1) A force exerted on the motor support points in the opposite direction to an action force from the motor

(*2) A motion to reposition the read head to a specific track on a platter

1.18 Improving Overcurrent Tolerance of SiC MOSFETs Through Device Design Optimization and Protection Circuit



Gate voltage control system for surge current protection



Improvement of overcurrent tolerance via device design optimization and protection circuit

There is an increasing need for silicon carbide (SiC) metal-oxide-semiconductor field-effect transistors (MOSFETs), next-generation power devices that are expected to contribute to power loss reductions in power grids, electric vehicles, railways, and other electrical systems. However, SiC MOSFET overcurrent tolerance decreases when applied for synchronous rectification.

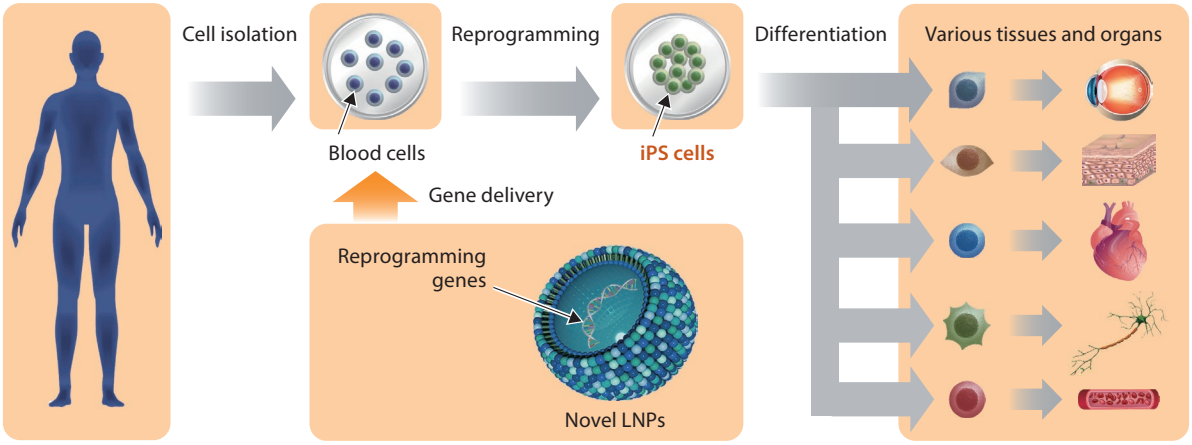
To solve this issue, the Toshiba Group performed a simulation analysis which revealed that the SiC MOSFET operates in bipolar mode during normal rectification and in unipolar mode during synchronous rectification, resulting in excessive heat generation and reduced overcurrent tolerance.

Based on the results of our analysis, we optimized the device design to induce bipolar operation in overcurrent conditions. We confirmed that the new device provides 1.6 times greater overcurrent tolerance than the previous device. Furthermore, we developed a protection circuit that inverts the gate voltage from positive to negative when it detects an overcurrent condition,

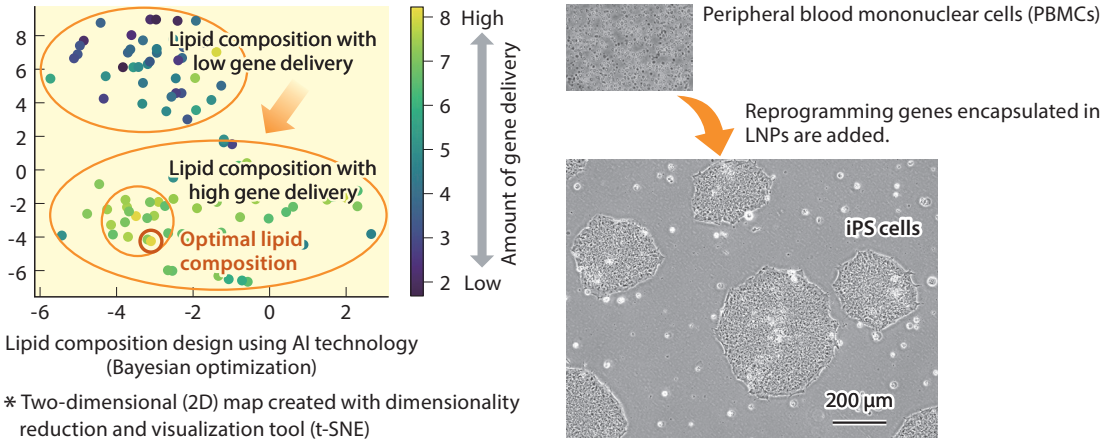
which further improved the SiC MOSFET overcurrent tolerance, increasing it to 2.4 times that of the previous device. The optimized device design and the new protection circuit will improve SiC MOSFET reliability and contribute to power electronic system stability.

The above results were achieved through joint research with Toshiba Electronic Devices & Storage Corporation.

1.19 Successful Generation of iPS Cells from Blood Cells Using Novel Lipid Nanoparticles



iPS cell production process using novel lipid nanoparticles (LNPs)



Novel LNP lipid composition design method and iPS cells produced from blood cells

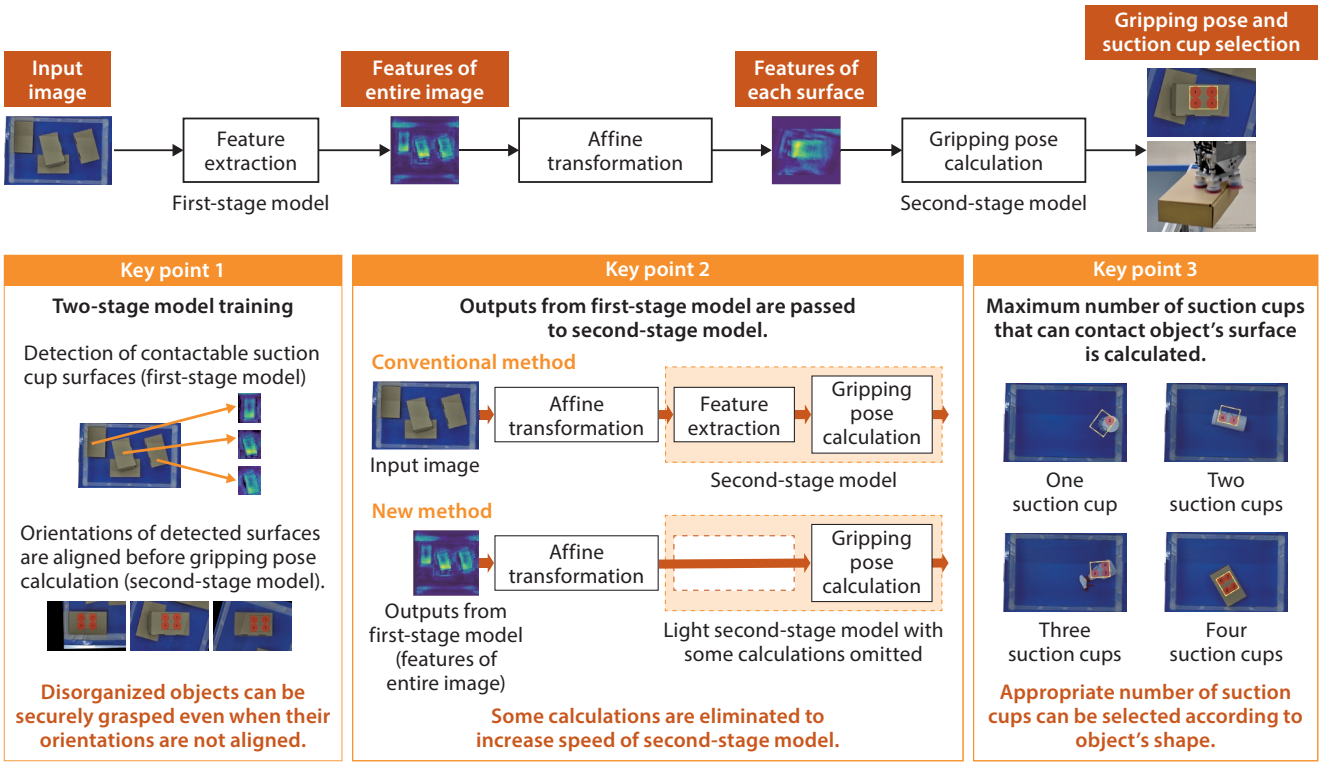
Induced pluripotent stem (iPS) cells capable of differentiating into almost any cell type, including tissues and organs, are expected to be useful for regenerative medicine and drug discovery. To facilitate the practical use of iPS cells in medicine, it is imperative to establish a production process that ensures their safety and uniformity. However, the current methods involving the use of viruses raise safety concerns.

To solve this issue, the Toshiba Group has developed an iPS cell production process using our novel lipid nanoparticles (LNPs) in collaboration with CiRA Foundation. LNPs are gene delivery vehicles composed of multiple lipid components. The gene delivery efficiency can be enhanced by optimizing the lipid component ratio according to the target cells. Leveraging AI technology, we designed LNPs with the optimal lipid composition to deliver genes to peripheral blood cells at more than 95% efficiency. We utilized these LNPs to encapsulate reprogramming genes(*), successfully generating iPS cells from blood cells.

The iPS cell production process using LNPs is anticipated to have broader applications thanks to its safety and scalability. In the future, we aim to produce cells for various tissues and organs from iPS cells.

(*) Genes responsible for resetting a cell's gene expression to generate iPS cells

1.20 AI Model for Rapid Gripping Pose Calculation for Robotic Multi-Suction Cup Grippers to Securely Grasp Target Objects of Various Shapes

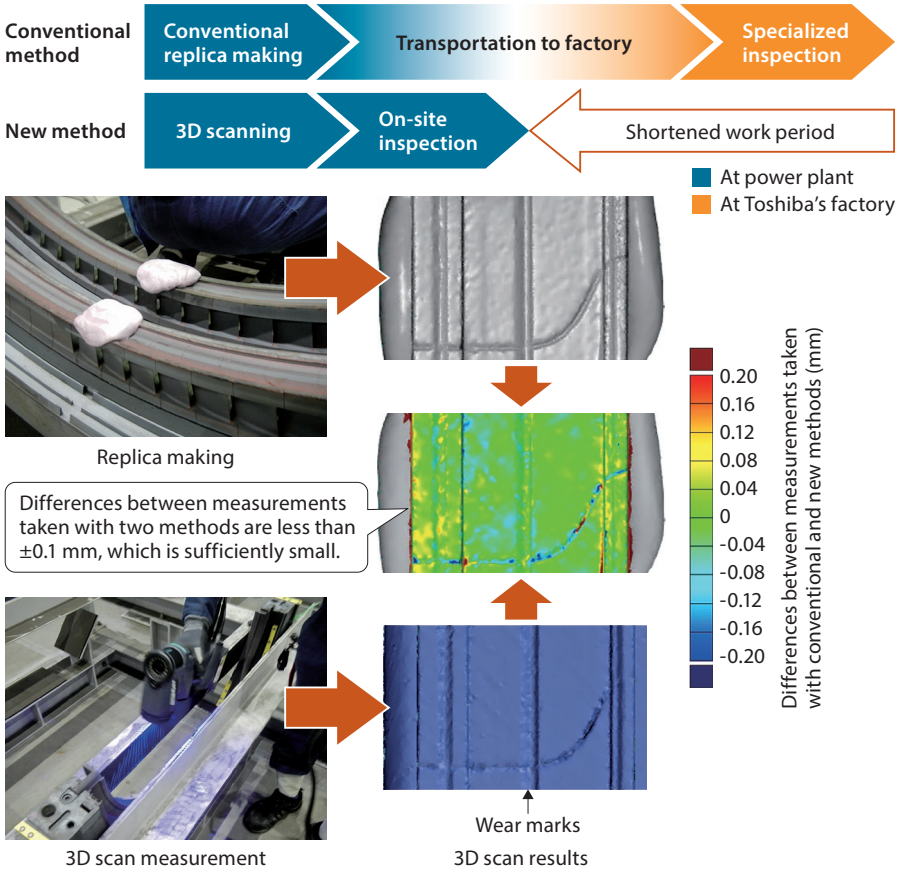


Overview of AI model to rapidly provide gripping poses for robotic multi-suction cup grippers

To compensate for labor shortages, there is an ever-growing need for robots capable of automating warehouse picking tasks. In response, the Toshiba Group is developing robots with a multi-suction cup gripper. However, the conventional method took 5.62 seconds to calculate a robot's gripping pose to grasp disorganized objects (with a 73.9% success rate), so speed improvements were essential.

To solve this issue, we have developed a two-stage AI model for rapid gripping pose calculation. In the first stage, the AI model detects the object surfaces that a robot's gripper can contact. The second stage takes the results of affine transformation from the first stage as input to determine the gripper's orientation and suction positions. The new AI model makes it possible to align the orientations of the detected surfaces, proving effective even for disorganized objects. Additionally, reusing the feature map derived from the first stage eliminated the need for some calculations in the second stage, resulting in faster processing. Moreover, the number of suction cups can be adjusted based on their contact areas to better adapt to the object's shape. Validation using images of typical warehouse items demonstrated significant improvements over the conventional method, reducing the computation time by more than 90% to 0.47 seconds and increasing the success rate by 6.2 points to 80.1%.

1.21 On-Site Wear and Damage Inspection at Thermal Power Plants Using 3D Scanner



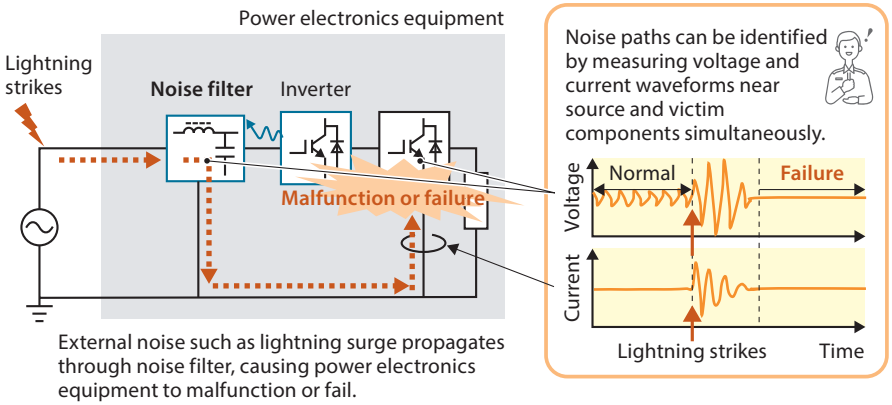
Comparison of conventional and new wear inspection methods

Conventionally, regular inspections of thermal power plants involved transferring the shapes of wear traces and damage of components onto replicas and bringing them back to a factory for measurement, resulting in long inspection periods.

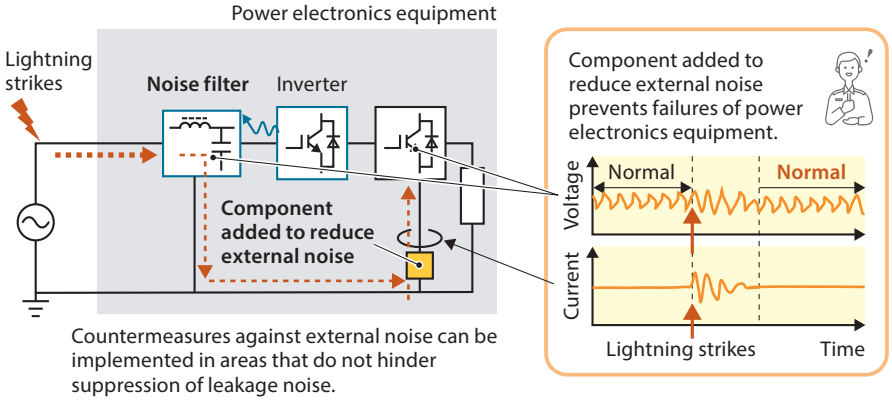
To complete wear and damage inspections on-site, Toshiba Corporation and Toshiba Energy Systems & Solutions Corporation have developed and introduced a new inspection method using a handheld 3D scanner, targeting the wear and damage on the surface layer of a turbine's stator vane fins. This new method provides accuracy equivalent to that of the conventional method and adopts a new positioning technique that does not affect the measured objects, enabling the use of a handheld 3D scanner. It allows inspections to be completed on-site, shortening the inspection period. Furthermore, while the conventional method provides only localized data, the 3D scanner allows for continuous and 3D evaluation of component shapes and wear conditions. This advancement is expected to help optimize component replacement timing.

We will continue to promote the utilization of 3D data to expand the maintenance business and streamline work.

1.22 Technology to Analyze Electromagnetic Noise Paths to Reduce Both Electromagnetic Interference and Susceptibility



Noise propagation path analysis technology

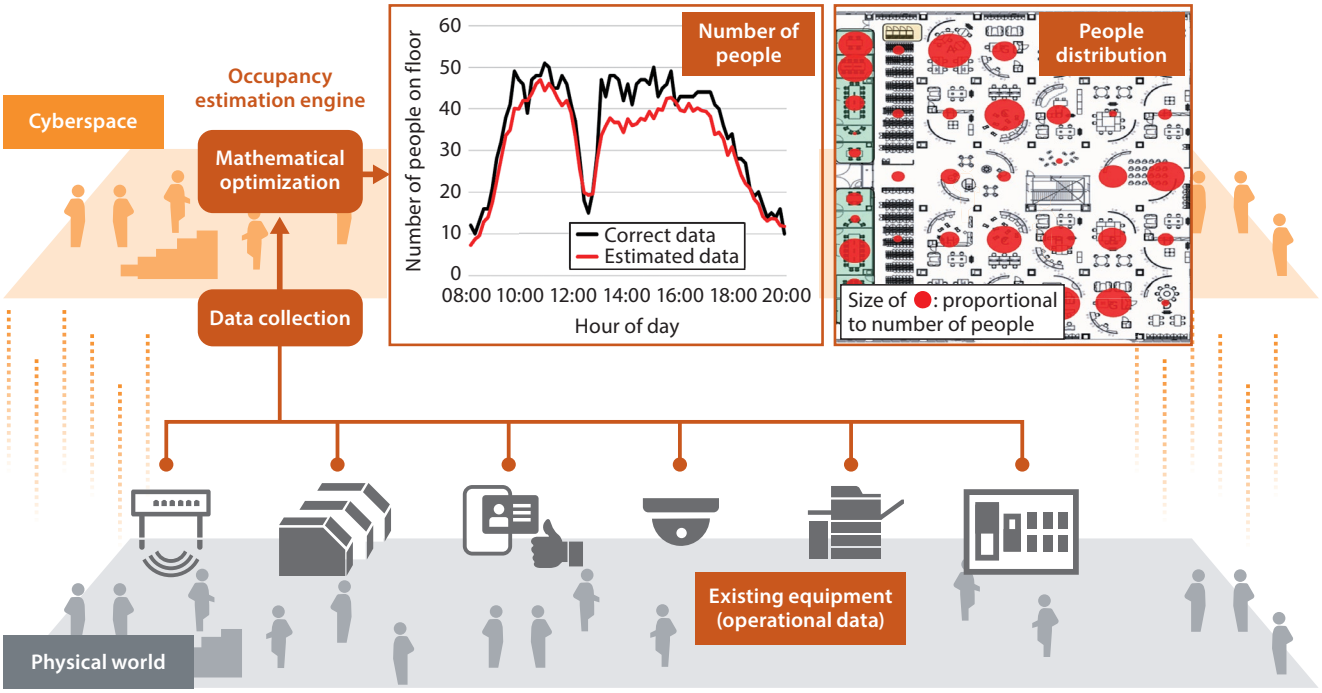


Measures for reducing leakage noise and reducing external noise

Driven by the growing demand for energy conservation, the switching speed of power electronics equipment such as inverters has been increasing, resulting in more electromagnetic interference (EMI) noise leakage. On the other hand, EMI filters sometimes create paths for external noise such as lightning surge, causing electronic components to malfunction or fail.

To solve this issue, the Toshiba Group has developed technology to analyze the paths of EMI noise and lower leakage while reducing susceptibility to external EMI noise. The technology can clarify the EMI noise paths to victim components by using differential probes to observe the voltage waveforms of both source (filter) and victim components as well as the current waveforms of the coupling wires between the source and victim. This makes it possible to implement countermeasures against external EMI noise in areas that do not hinder the suppression of EMI noise leakage. Using the new analysis technology early in the design process helps design low-noise power electronics equipment. Also, in the event of a test fail, the new analysis technology facilitates failure analysis and countermeasures, reducing development iterations.

1.23 Occupancy Estimation Engine Utilizing Existing Equipment as Virtual Sensors



Configuration of floor occupancy estimation engine deployed in Innovation Palette

With the advancement of IoT and AI technologies, digital twins are attracting much attention as a means of monitoring floor occupancy. The Toshiba Group has developed an occupancy estimation engine as a software module for office buildings, commercial facilities, and other buildings. It shows the number of people and their distributions on the floor based on operational data from equipment such as wireless local-area network (WLAN) systems and entrance gates.

The new occupancy estimation engine offers various business solutions. For example, it helps to save electricity by controlling lighting and air conditioning according to room occupancy and facilitates space management, area-specific advertising, and enhanced security. Its most distinctive feature is using existing equipment as virtual sensors, eliminating the need to install additional sensors and thus reducing solution implementation costs considerably.

The new engine estimates room or floor occupancy by collecting operating data from equipment influenced by human activities, converting them into a headcount, applying mathematical optimization methods to minimize data inconsistencies, and calculating occupancy in arbitrary zones. The estimation accuracy can be greatly improved by using operational data from multiple types of equipment.

We performed a demonstration at Innovation Palette(*), a 50×70 m office with a capacity of approximately 200 seats. Using data from more than five types of existing equipment such as WLAN systems, entrance gates, ceiling cameras, and power distribution boards, we verified

the occupancy estimation accuracy under various data conditions. The estimated number of people on the floor changed according to the occupants' activities during the day with an average error of less than 10%. The average absolute error in the distribution in each zone was 0.6 people.

The engine provides occupancy estimation in real time, and we will offer it as a cloud service and an on-premises solution according to requirements and existing equipment constraints.

(*) New Toshiba Group R&D facility completed in November 2023

1.24 Launch of Meister Apps to Improve Manufacturing Process of Electronic Circuit Boards through Data-Driven Methods

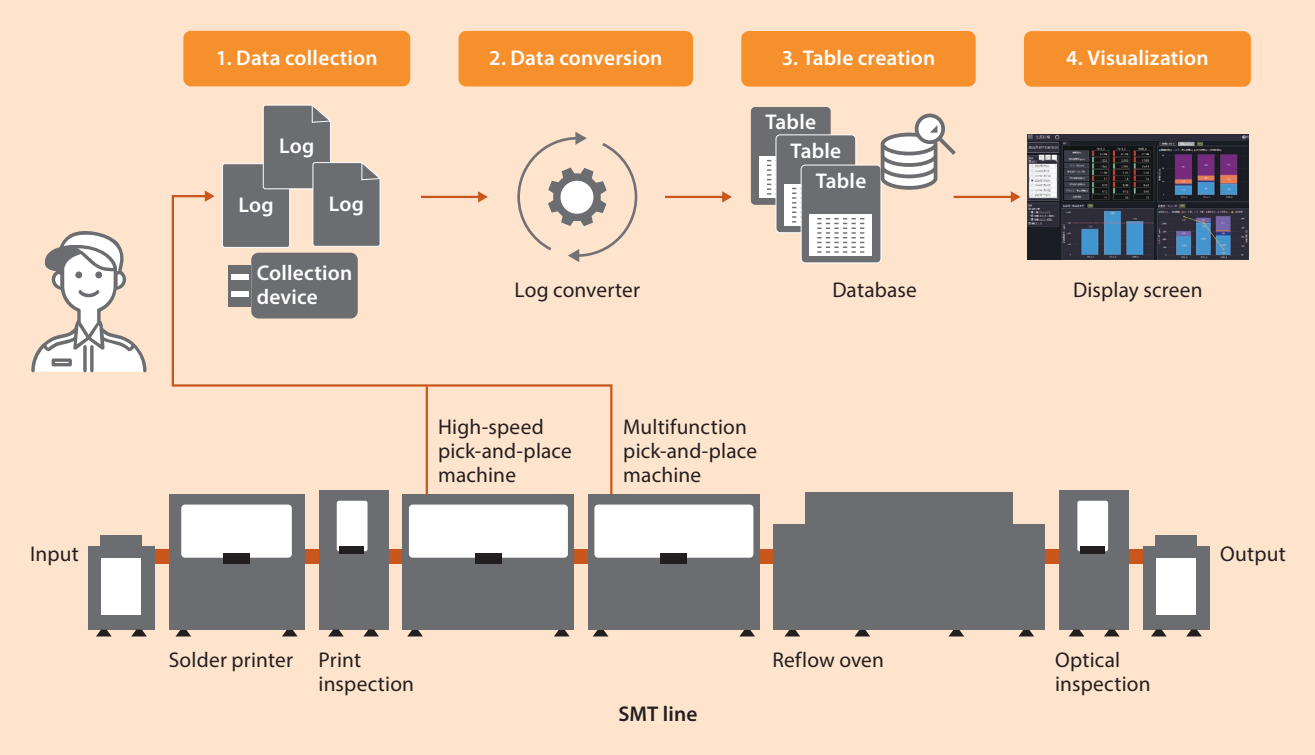
In recent years, smart factories have made advances in improving product quality and reducing costs. It is difficult, however, to convert electronic circuit board production lines to smart versions because they consist of equipment from different manufacturers and eras.

Toshiba Corporation and Toshiba Digital Solutions Corporation have developed technology to streamline electronic circuit board manufacturing. It was launched in October 2024 as a new Internet-of-Things (IoT) solution called the Meister Apps Process Improvement Assist Package for SMT Lines (hereinafter "Meister Apps").

Meister Apps first collects log data from a pick-and-place machine, a piece of equipment used to place electronic components onto circuit boards in surface-mount technology (SMT) lines. Then, Meister Apps visualizes and analyzes process conditions to help improve worker efficiency and optimize quality control. Meister Apps can also handle production lines with mixed equipment from different manufacturers and eras. Additionally, its visualization menus can be customized to suit various manufacturing scenarios.

During the development process, we continually improved Meister Apps through trials at our own factories. Specifically, we built a system to collect log data from equipment from different manufacturers and eras for conversion into unified indicators in real time. In scrutinizing and integrating the collected data, we utilized our extensive knowledge of electronic circuit board manufacturing. Additionally, we developed algorithms to visualize and analyze operating status, component discard rates, and error rates for use in quality improvement activities at factories. Furthermore, we implemented a dashboard display based on feedback from our factory workers to enhance production management efficiency. For example, the dashboard can display operating and error rates in numerical and bar graph formats and provide summarized information for each production lot.

We will continue to develop new features to facilitate improvement activities in the manufacturing field and update Meister Apps.

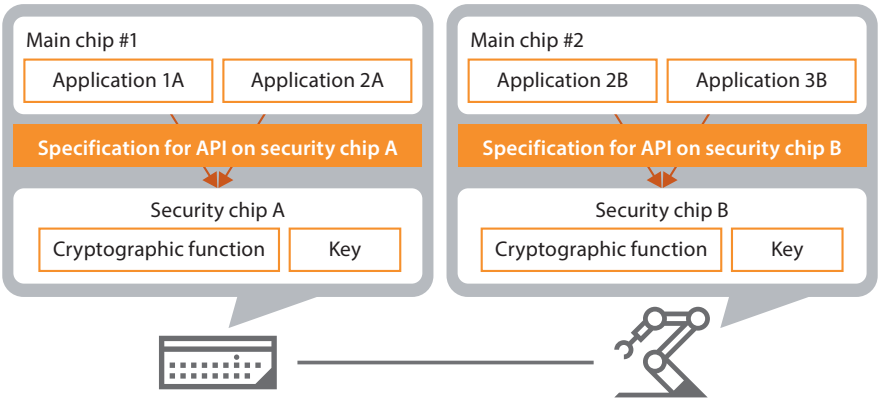


Configuration of prototype Meister Apps Process Improvement Assist Package for SMT Lines

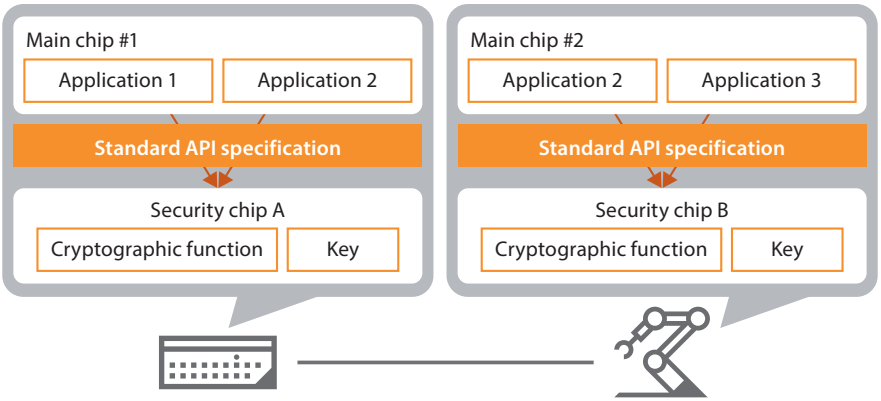
KPI: key performance indicator

Display screen image of Meister Apps Process Improvement Assist Package for SMT Lines showing manufacturing knowledge

1.25 Development of ISO/IEC TS 30168 API Standard for Integration of Secure Elements within Industrial IoT Devices



(a) Before applying standard API specification



(b) After applying standard API specification

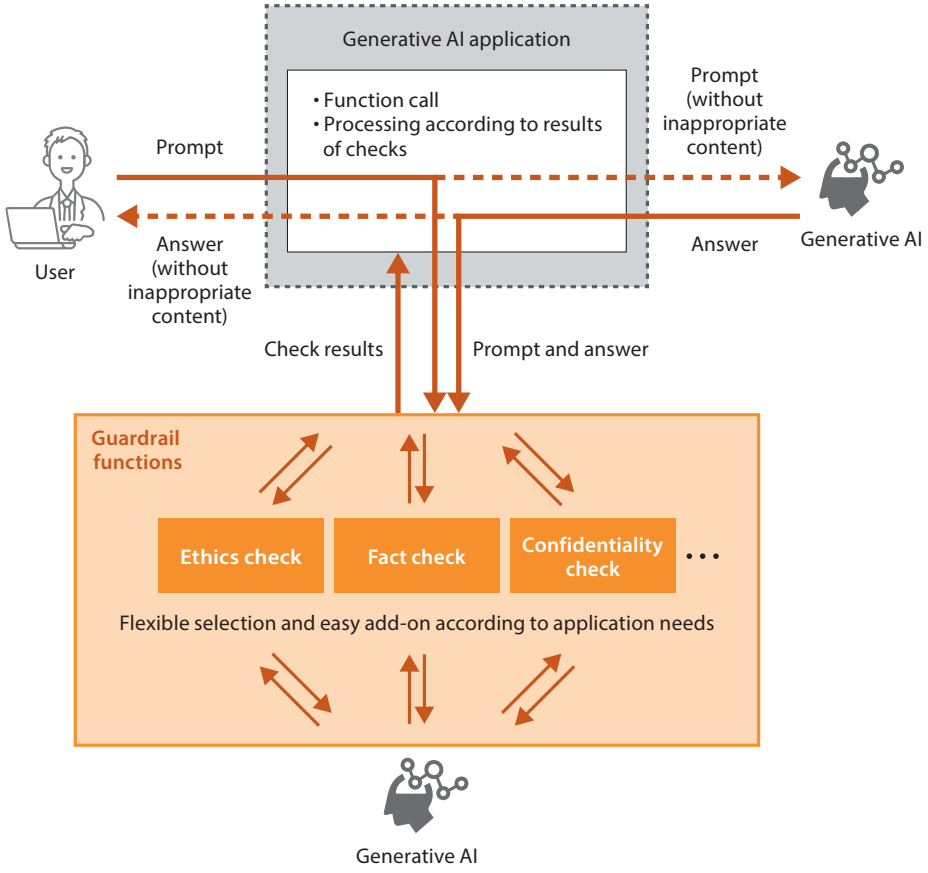
Standard API specification example

Security chips embedded in industrial IoT devices are designed to prevent the leakage of device-specific secret keys. These chips provide several security functions, including device authentication to allow only authorized devices to access a system, secure boot to ensure that the OS and applications are not tampered with during the startup process, and application authentication to prevent the execution of unauthorized applications.

However, security chips are not widely used because the API specifications for these security functions are specific to the chip vendor, making them difficult to use for application developers without security expertise.

To solve this issue, the Toshiba Group promotes the standardization of API specifications, acting as a co-editor of International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Technical Standard (TS) 30168 published in May 2024. Security chips compliant with this standard will make it possible even for those unfamiliar with security technology to incorporate security functions into industrial IoT devices, encouraging the widespread use of security chips and reducing risks to remote services.

1.26 Technology to Improve Answer Quality for Secure Utilization of Generative AI



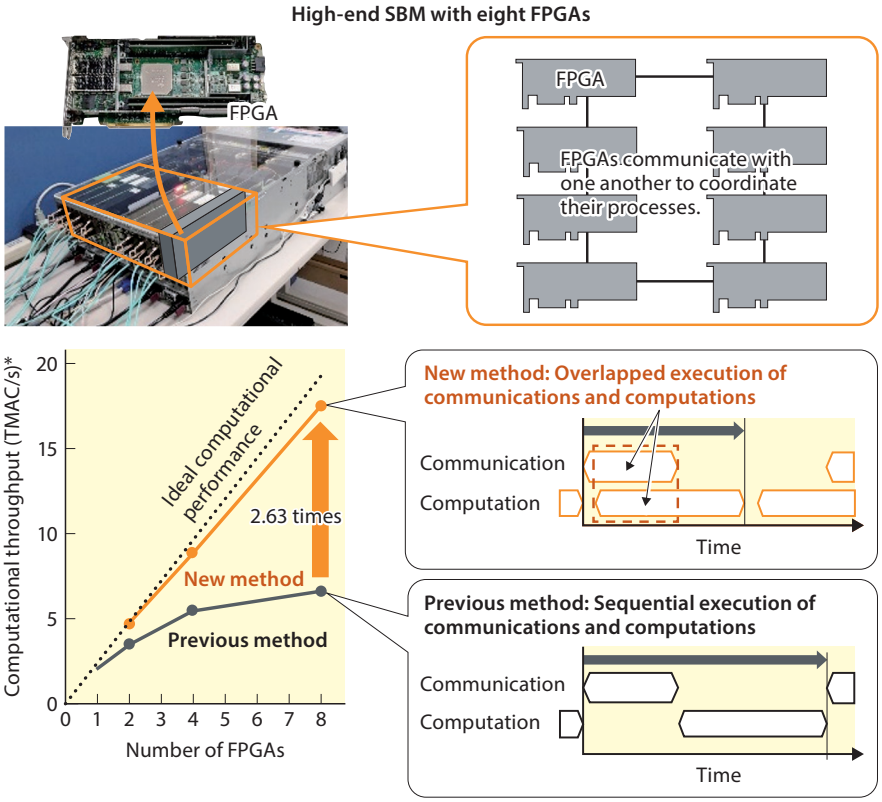
AI guardrails to check for inappropriate content

With the rapid evolution of generative AI and its widespread use in business applications to improve operational efficiency and reduce costs, there is a growing need for technologies that enable secure utilization of generative AI. One such technology is guardrails to monitor and control generative AI input (prompts) and output (answers) to prevent it from producing inappropriate information for users.

With this in mind, the Toshiba Group has developed a suite of guardrail functions to check for inappropriate content such as ethically harmful, factually incorrect, and confidential information. Because we offer these functions as selectable add-ons for business applications, users can easily build a series of AI processes, including those to check prompts and answers and suppress inappropriate content according to the results of checks, thereby enhancing application reliability.

In the future, we plan to incorporate the new guardrail functions into applications that utilize generative AI.

1.27 Scalable High-End Simulated Bifurcation Machine to Solve Large Combinatorial Optimization Problems



* Number of multiply-and-accumulate operations performed per second

High-end simulated bifurcation machine with near ideal scaling performance through overlapping computation and communication

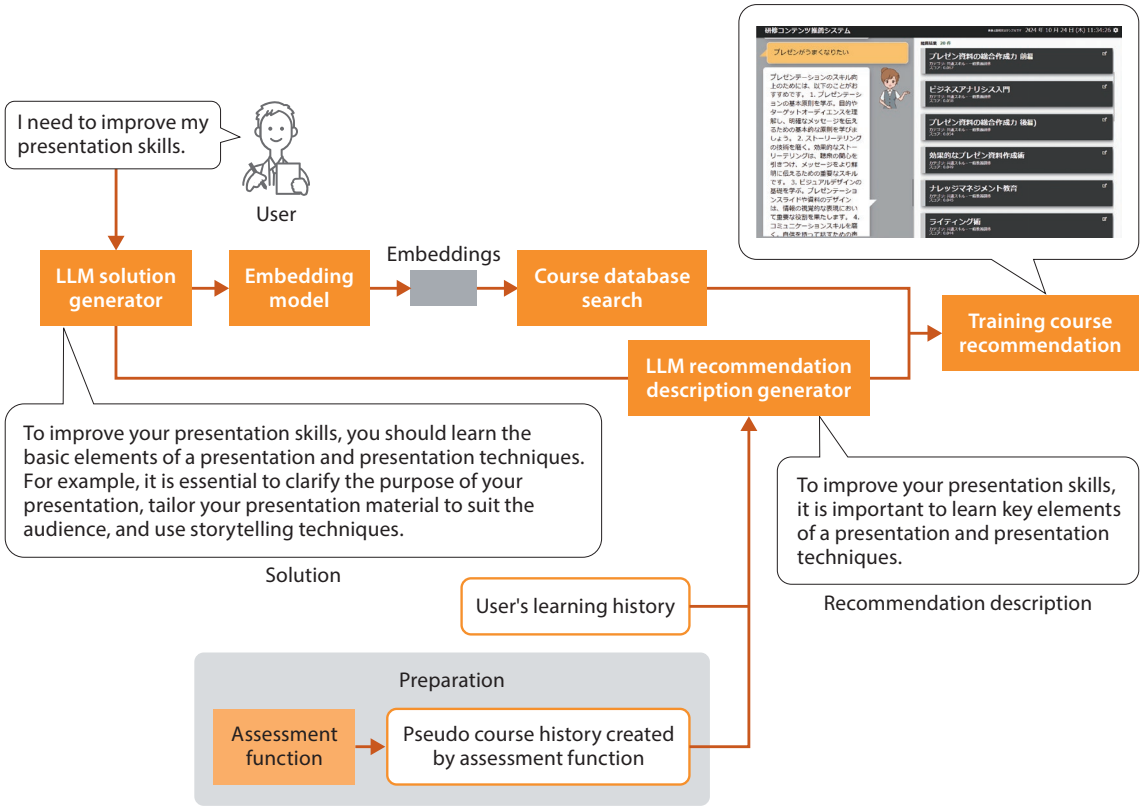
Combinatorial optimization problems are found in various application fields such as financial portfolio optimization and scheduling optimization. The larger the problems, the more difficult they are to solve.

Simulated bifurcation machines (SBMs), or Ising machines derived from Toshiba Group's quantum computer theory, can find approximate solutions to combinatorial optimization problems that are close to the exact solution in a short period of time. High-end SBMs are implemented with multiple field-programmable gate arrays (FPGAs)(*) to increase the solvable problem size and compute solutions to problems of various sizes in the shortest time. However, our previous SBM implementation could not fully utilize FPGAs computational power because of the communication overhead required to coordinate multiple FPGAs.

To solve this issue, we have developed a novel method to overlap inter-FPGA communications with intra-FPGA computations efficiently. This method makes it possible to scale the computational performance almost linearly with the number of FPGAs and reduce the time required to find solutions to large combinatorial problems.

(*) Integrated circuits that can allow users to reconfigure their internal logic

1.28 System to Recommend Appropriate Training Courses According to User Desires

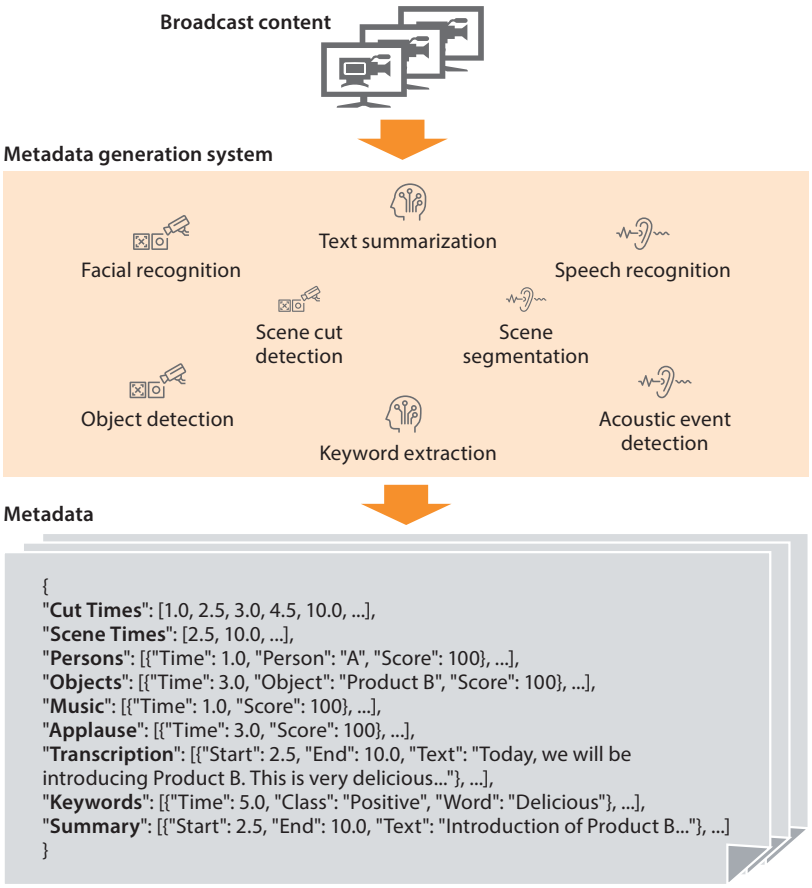


Overview of training course recommendation system

With the increasing prevalence of on-demand training courses, e-learning and other online training support services have been attracting attention. Many training materials contain specialized terminology or do not come with descriptive titles. For example, ambiguous titles like “Basic Management Course” make it difficult to find appropriate courses.

With this in mind, the Toshiba Group has developed a recommendation system based on a large language model (LLM) that recommends suitable training materials according to user desires. First, users describe their needs or situation in plain language, such as, “I need to improve my presentation skills” or “I am moving to the accounting department.” Then, the new recommendation system generates solutions with the LLM and searches for training materials similar to them. Next, the recommendation system estimates users’ proficiency levels based on their learning histories and assessment test results and eliminates the materials irrelevant to their skill levels. Through these processes, the system recommends training courses that match users’ desires and abilities from a large number of options. This system will be helpful in training diverse staff.

1.29 AI-Powered Metadata Generation for Broadcast Data Management



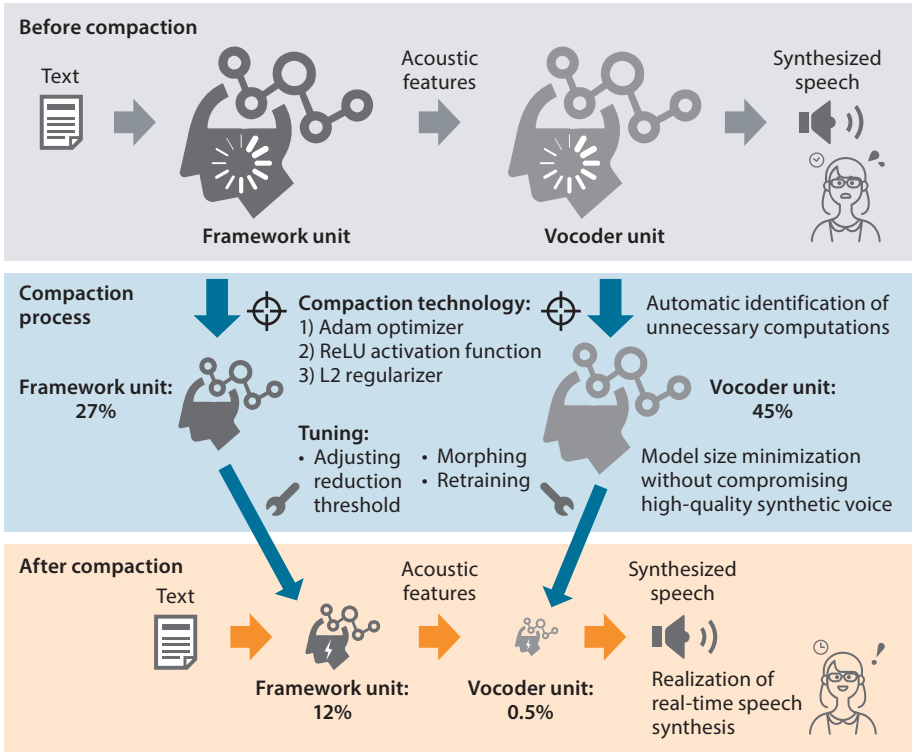
AI-powered metadata generation for broadcast data management

Broadcast metadata include information about TV programs and other content such as cast and featured products. Metadata are essential to facilitate secondary uses and make it easier to organize and search broadcast content, thereby maximizing value. At present, however, it is necessary to prepare metadata manually, incurring significant costs.

To solve this issue, the Toshiba Group is developing a platform that automatically generates, accumulates, and provides broadcast metadata using our cutting-edge AI technology. It generates broadcast metadata by performing scene segmentation via image and sound analysis, identifying individuals and featured products via facial and object recognition, detecting acoustic events such as applause and background music via deep learning models, transcribing speech to text via speech recognition, and extracting keywords and scene summaries using generative AI technology.

Using TV metadata, we automatically generated promotional materials such as in-store point-of-purchase (POP) advertisements and digest movies for real store products. In a proof-of-concept experiment, this approach resulted in an approximately threefold increase in revenue compared to the case of not using TV metadata.

1.30 Increasing Speech Synthesis Middleware Speed by Compacting DNN Models



Adam: adaptive moment estimation ReLU: rectified linear unit

Overview of compaction of DNN model for speech synthesis

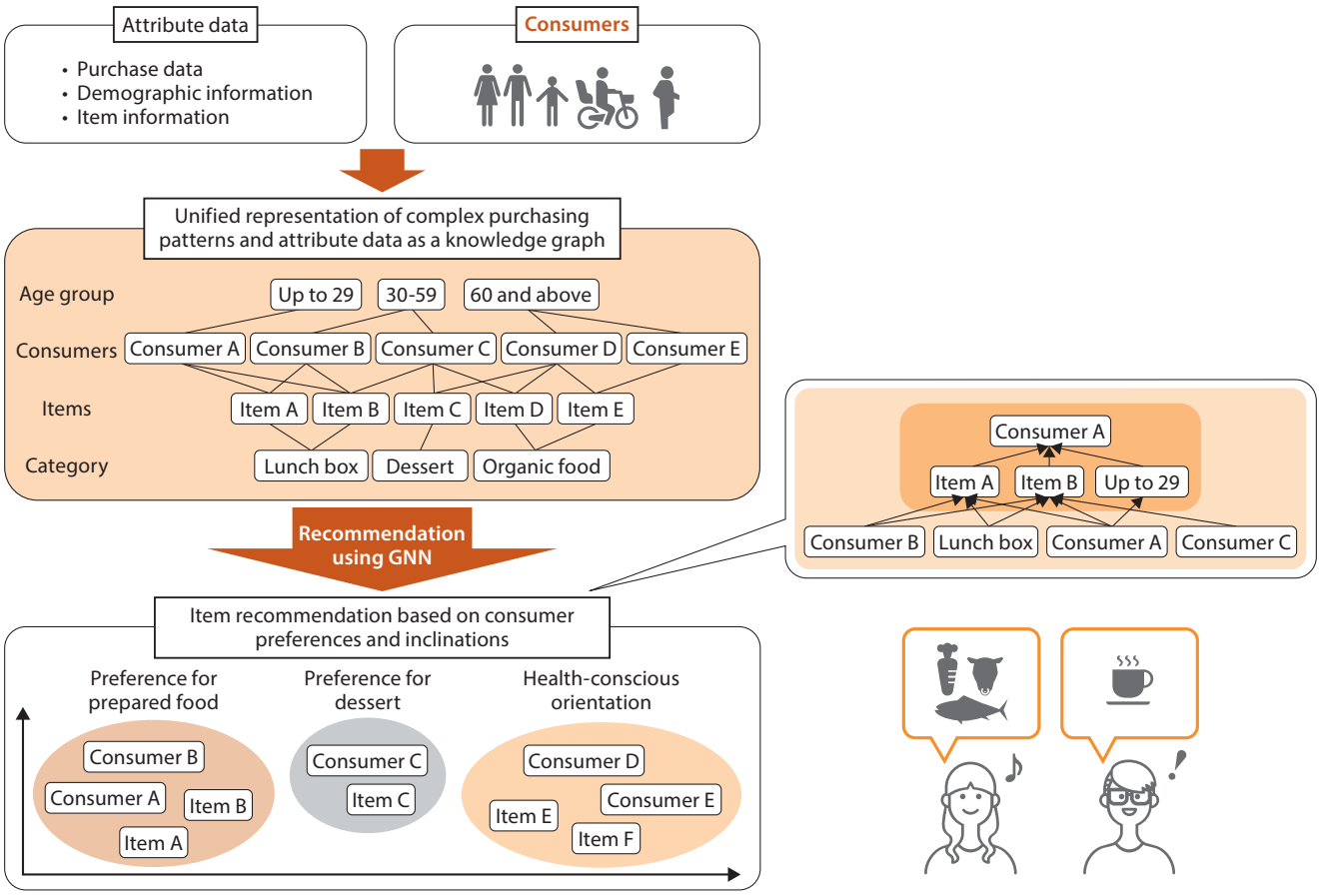
The Toshiba Group has developed unique technology to compact deep neural network (DNN) models, which automatically identifies and removes unnecessary computations during model training. It uses general learning methods (1 to 3 in the figure) to reduce computational workloads without compromising the middleware performance.

We applied the new technology to the DNN models used in the ToSpeak Hx Pro Version 1.00 series of high-end ToSpeak RECAIUS speech synthesis middleware, achieving reduced computational load and increased speech synthesis speed in a short period of time.

Traditional DNN model compaction methods required numerous trials and errors, involving a process of identifying redundant parameters by reducing some parameters and measuring the resulting performance. The new technology eliminates the need for time-consuming manual trials and errors, making it possible to reduce both the model size and computational load efficiently.

The speech synthesis DNN models consist of a framework unit model that obtains acoustic features from text and a vocoder unit model that synthesizes speech waveforms from the acoustic features. Tuning using the new technology reduced the sizes of the framework and vocoder unit models to only 12% and 0.5% of their respective uncompacted models without compromising high-quality synthetic voice, enabling real-time speech synthesis.

1.31 Item Recommendation Technology Using Consumer and Item Attribute Data



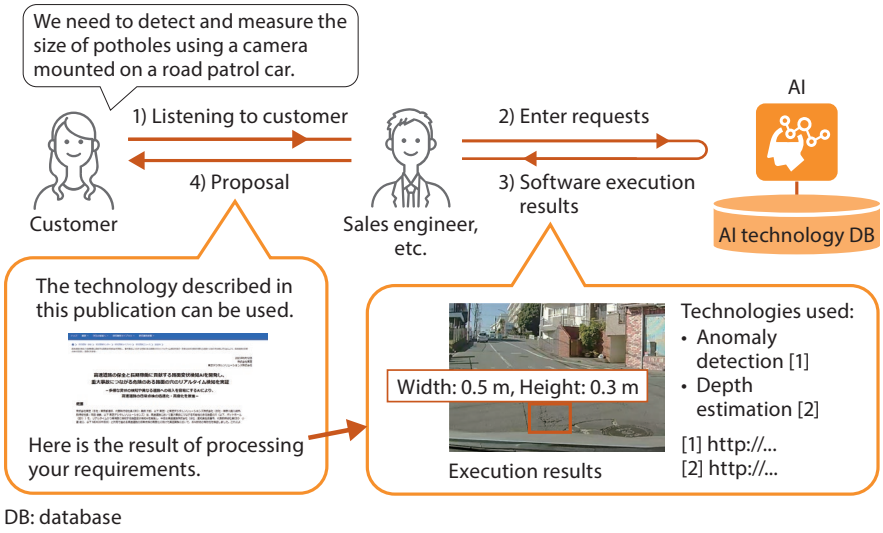
Overview of item recommendation system using attribute information

To strengthen the data business, the Toshiba Group is promoting the utilization of purchasing data. We have also recently gained access to attribute data, including gender and product categories, driving growing demand for high-performance purchasing data analysis techniques that leverage various attribute data.

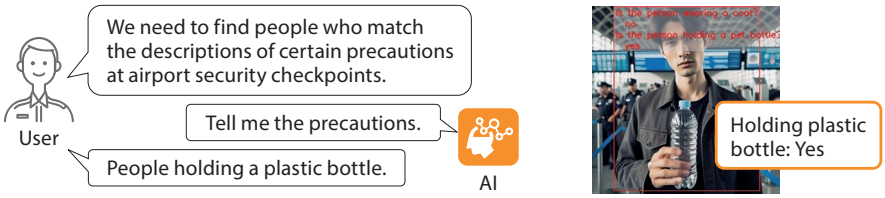
However, the effectiveness of conventional techniques is often constrained by the need to manually select useful attribute data and then determine how to utilize each type. To resolve this issue, we have developed an item recommendation system that automatically selects the necessary attribute data, constructs a knowledge graph, and leverages graph neural networks (GNNs) to identify complex shopping patterns. Our analysis of recommendations using actual purchasing data confirmed that the new system can recommend items based on consumer characteristics such as preferences for prepared food, dessert, and health-oriented choices.

Our next step is to offer one-on-one marketing by tailoring approaches to individual needs using this new technology. We will explore its applications in collaboration with Toshiba Tec Corporation, including optimizing shopping coupon distribution to enhance sales promotion effectiveness.

1.32 Interactive AI Technology to Generate Software Automatically from Ambiguous Requests



AI technology supporting technical proposal work



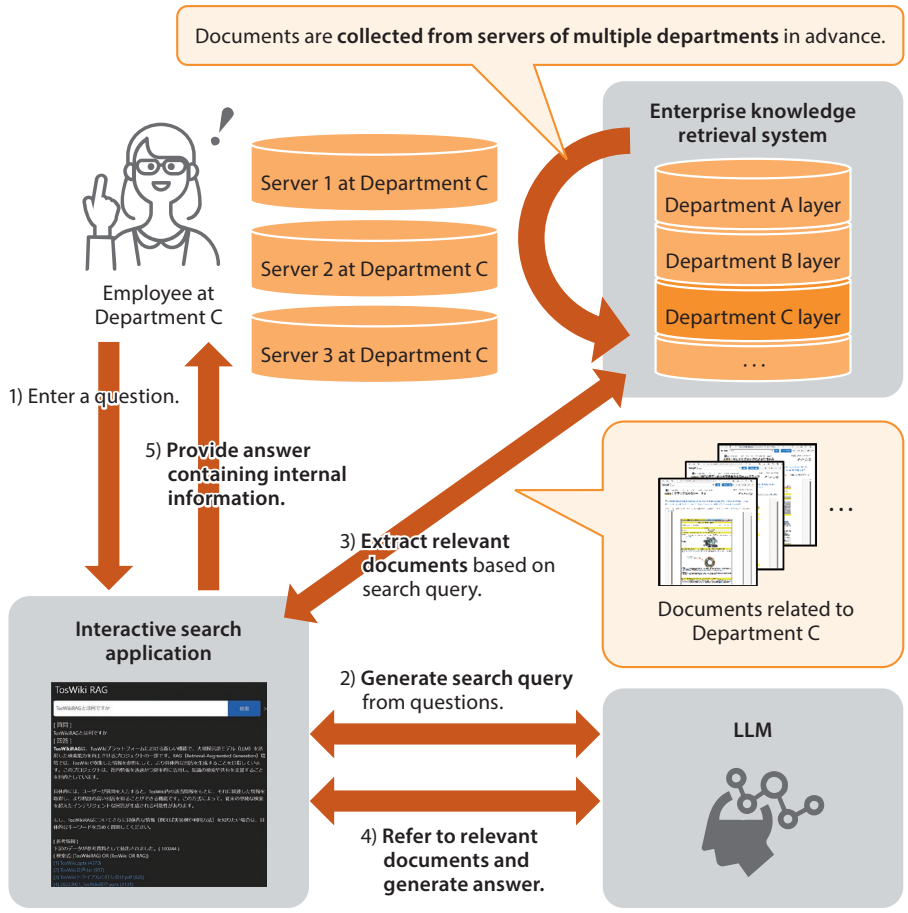
Example of software generated through dialog

Customer issues are becoming increasingly complex, necessitating a wide range of knowledge and skills to solve them. For example, even a single task such as proposing a software solution that satisfies a customer's requests involves clarifying ambiguous requirements, identifying appropriate technologies to be used, and establishing a test environment. This means that a significant amount of time is required to formulate a proposal.

To support these tasks, the Toshiba Group has developed AI technology which provides two main functions: (1) clarifying ambiguous required software specifications through dialog, and (2) automatically generating complex software incorporating multiple technologies. The second function selects the right technologies from our technical assets based on the clarified requirements. Experiments have confirmed that the new AI can generate software according to the customer's requests even when they are ambiguous and wide ranging.

The new AI technology contributes to improving software quality, reducing costs, and shortening the proposal and software development lead times, thereby enhancing customer value. It also enables co-creation with customers using both our own and our customers' technical assets.

1.33 Enhancing Business Operation Efficiency through Integrated Use of Enterprise Knowledge Retrieval System and Large Language Model



Enterprise knowledge retrieval system and communication with LLM

In recent years, the application of LLMs in corporate information retrieval has enabled rapid and efficient extraction of information necessary for business operations. The application of LLMs is expected to significantly improve both efficiency and productivity within organizations. When handling corporate information with an LLM, it is necessary to implement robust security measures, such as access permissions, to ensure that sensitive data are adequately protected. Additionally, a unified access method is required to seamlessly reference corporate information scattered across multiple distributed servers.

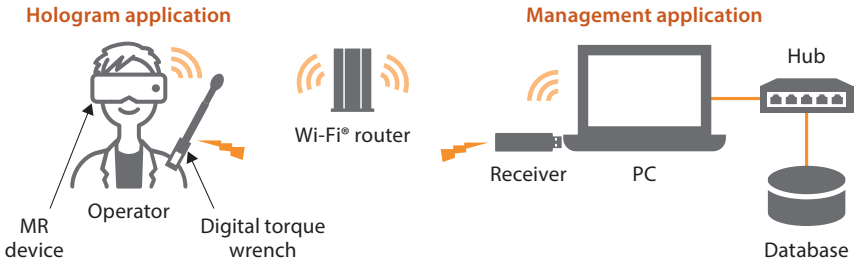
To solve these issues, the Toshiba Group has developed a secure and efficient enterprise knowledge retrieval system by integrating an information-sharing platform with an LLM. The new system allows comprehensive keyword-based document retrieval from multiple distributed servers while adhering to a user's file security permissions. Using this system helps achieve an integrated LLM-based search environment in a relatively short period of time. First, the LLM generates keyword search queries from a user's questions, and then a new search

application extracts relevant documents efficiently. Next, the LLM generates detailed answers to the user's questions, referring to the extracted documents.

Using the new search environment with actual data, we have evaluated its accuracy and response speed for business-related inquiries.

We will further enhance the convenience of this search environment to improve business efficiency.

1.34 Manufacturing Assistance Technology Using Mixed Reality



Overview of screw fastening solution

Example of real parts and virtual objects being fastened with screws

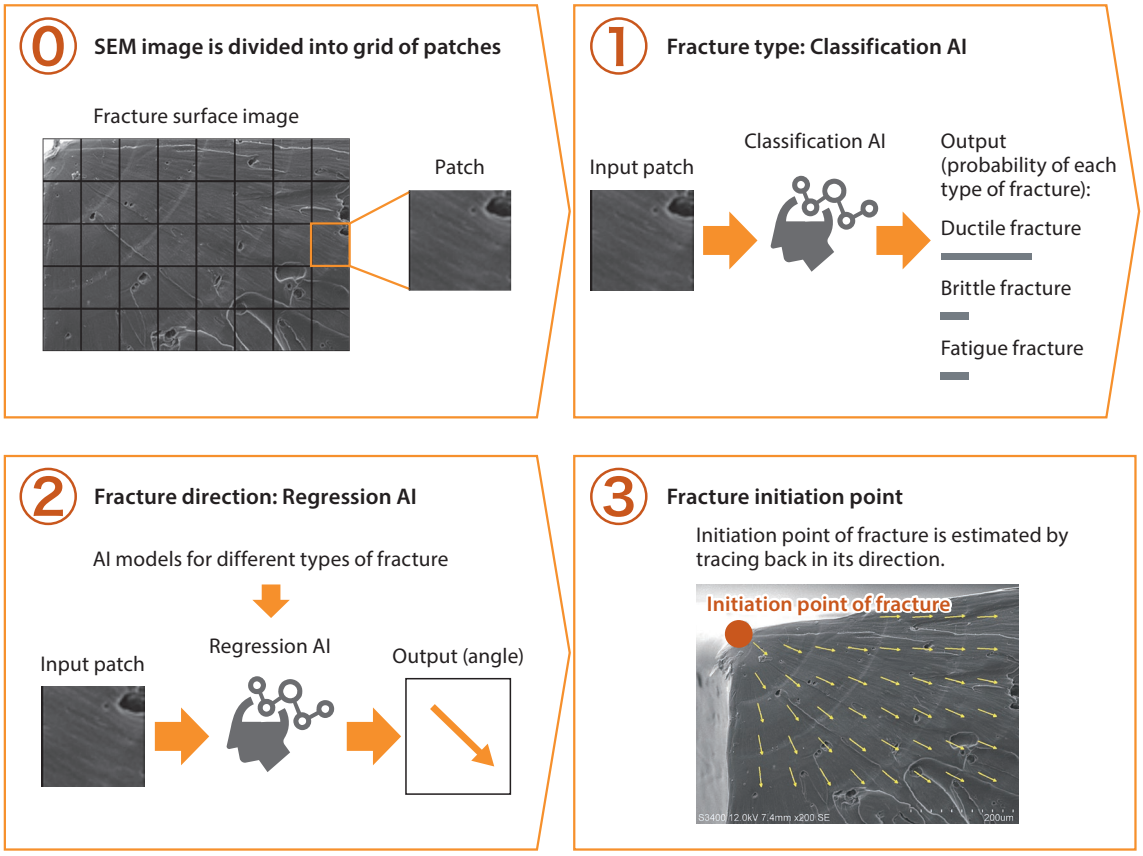
Traditionally, to avoid missing screws during the manufacturing process, multiple operators cross-checked their tasks. To ensure work quality independent of human factors, improve work accuracy, and reduce work hours required for screw fastening operations, the Toshiba Group has developed work assistance technology using a mixed reality (MR) device, digital torque wrenches, and an internal server database.

To identify the exact location where screws are required, the hologram application on the MR device displays a mixed reality image, superimposing virtual object images over real parts. This helps improve work accuracy, reduce the time required for worker training, and ensure work quality.

We have also developed a management application that collects screw number and tightening count data from the MR device as well as tightening torque data from digital torque wrenches and automatically determines whether the torque has reached the preset value for each screw. The results are then stored in the database.

In the future, we plan to develop a system to visualize database information and use it as work evidence.

1.35 Fractography AI for Efficient Fracture Analysis



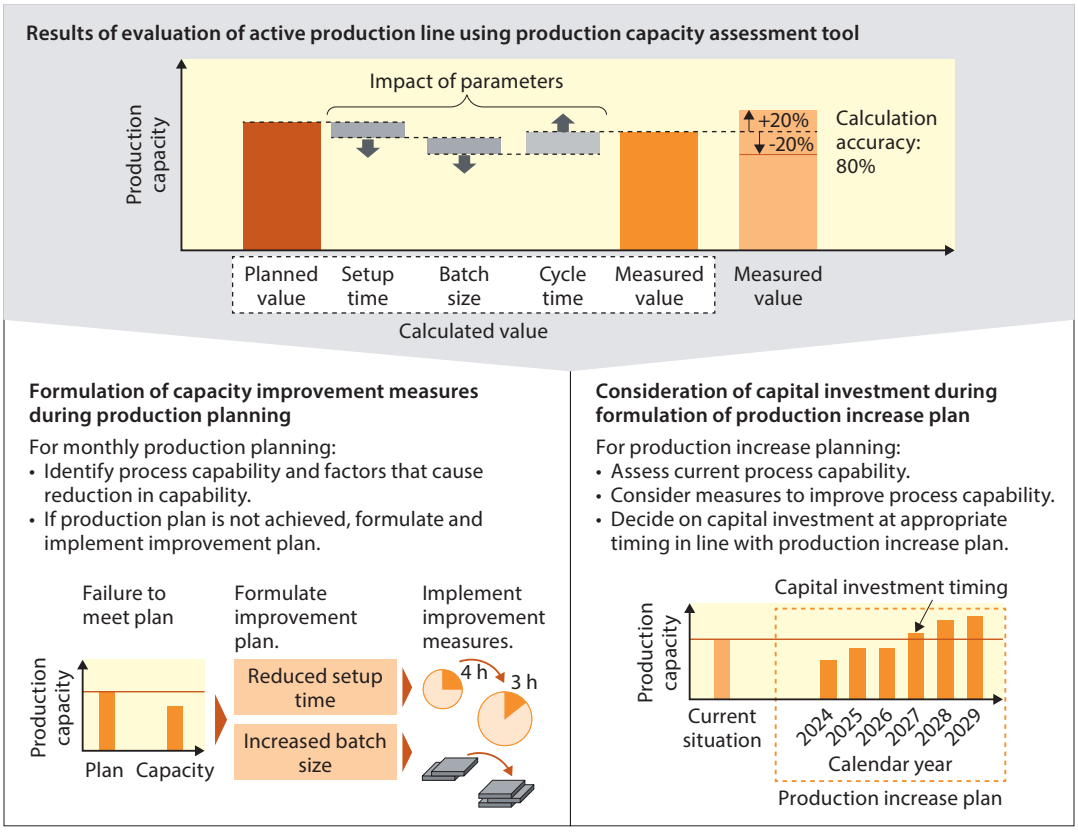
Overview of fractography AI for efficient fracture analysis

Fractography is used to determine the cause of fracture in resin and metal materials and provide feedback for design and manufacturing teams to improve product quality. In fractography, a scanning electron microscope (SEM) is employed to identify the type, direction, and initiation point of fracture. Automation of fractography is desirable as the process requires specialized, time-consuming analysis.

The Toshiba Group has developed fractography AI that automatically estimates the fracture type, progression direction, and initiation point from SEM images. The new AI system divides an SEM image into a grid of patches, estimates the type and direction of fracture in each patch using convolutional neural networks (CNNs), and then traces back the estimated fracture direction in each patch to determine the initiation point. When verifying the process, we confirmed that the new AI system estimated the type of fracture with an average accuracy of 97.6% and the progression direction with an accuracy of 80.3 to 92.0%, depending on the fracture type. The initiation points determined by the new AI system were close to those determined by human experts.

This fractography AI significantly reduces the time required to determine the cause of fracture and enables efficient feedback to design and manufacturing.

1.36 Deployment of Production Capacity Assessment Tool on Production Lines



Production capacity improvement using production capacity assessment tool

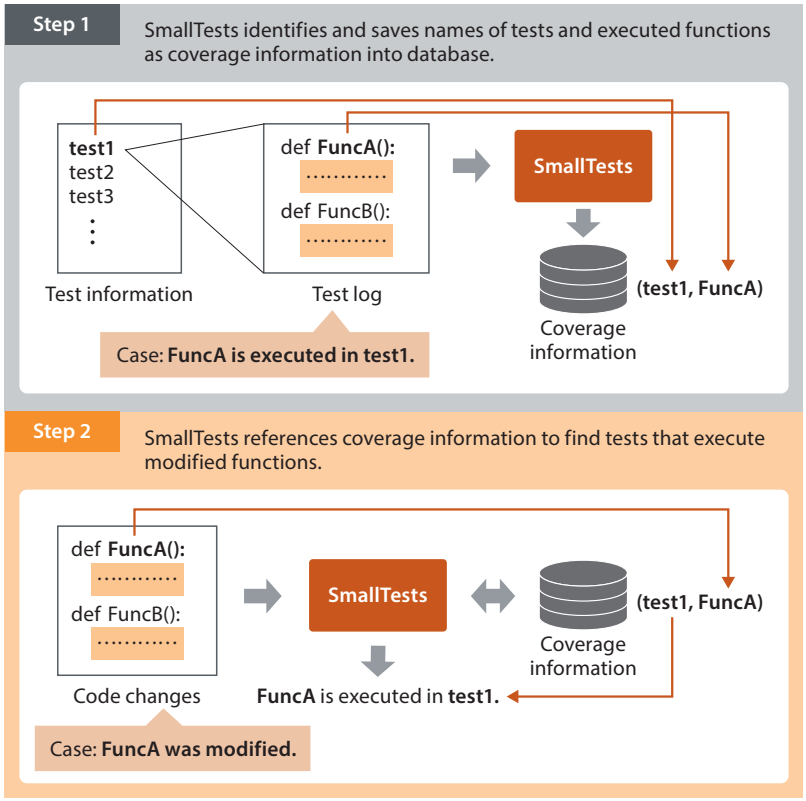
The method for calculating production line capacities depends on the manufacturing process, complicating overall production capacity adjustment and sometimes resulting in reduced calculation accuracy. To address these issues, the Toshiba Group has developed an easy-to-use, high-precision production capacity assessment tool.

The new tool calculates both planned and actual process capacities and visualizes parameters causing deviations between the planned and actual values and their impacts. This makes it possible to quickly grasp available production capacities and provide guidance for operational improvements. The production capacity assessment tool facilitates the formulation of capacity improvement measures to achieve production plans. It also simplifies the consideration of appropriate specifications and timing for equipment investment when planning to increase production in the future.

We calculated the capacity of an active production line using the new tool, achieving a calculation accuracy of more than 80% for all processes. Because the accuracy met the requirement for on-site deployment, we have started using the tool.

We plan to expand its scope of application and contribute to improving production planning accuracy and formulating equipment investment plans for various production lines.

1.37 SmallTests Service to Reduce Number of Regression Tests by Utilizing Coverage Information



SmallTests service for reducing number of regression tests

The Toshiba Group is introducing automated testing to maintain software quality and shorten development cycles. However, even with automated testing, a considerable amount of time is required to execute a large number of regression tests.

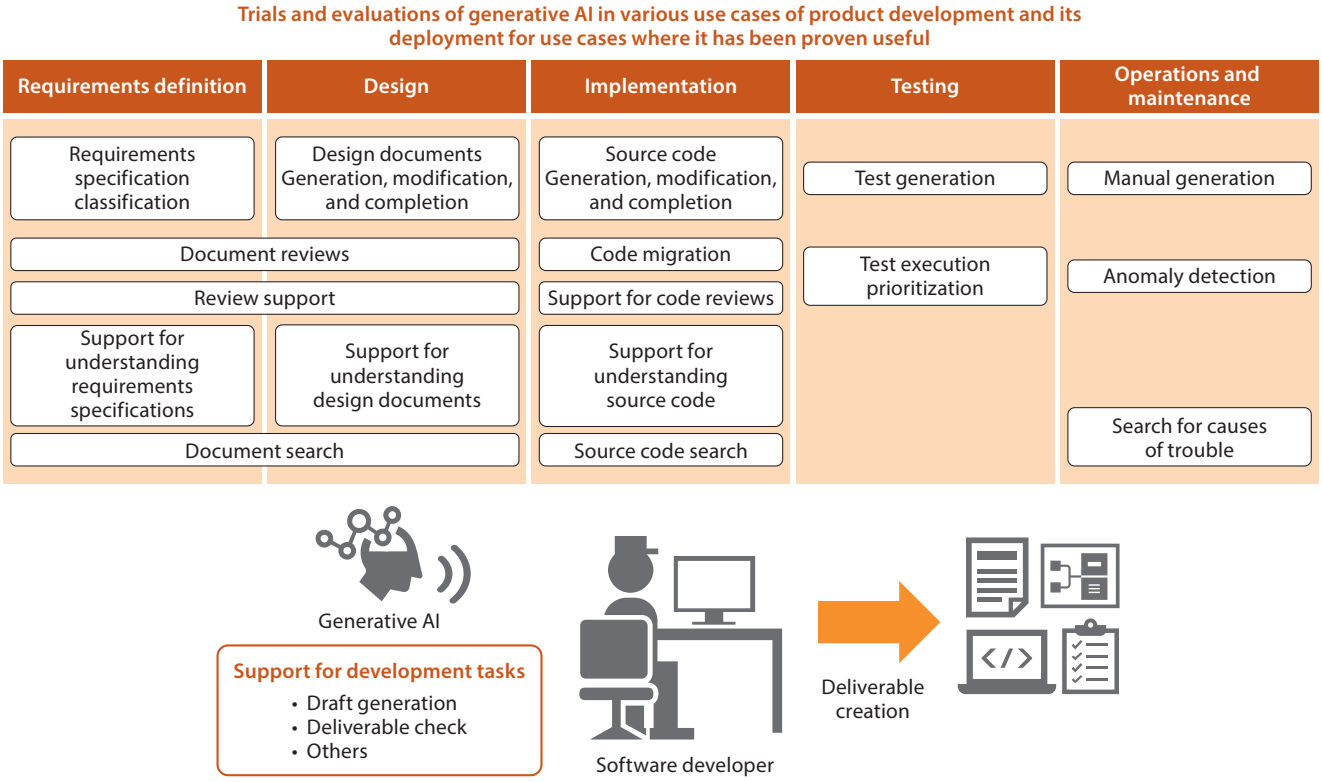
To address this issue, the Toshiba Group has developed SmallTests, a service to reduce the number of regression tests by utilizing coverage information. SmallTests consists of two steps:

- Step 1 (test execution): SmallTests collects coverage information from test logs created during each test session. Coverage information consists of the names of the tests and the functions executed in each test.
- Step 2 (test selection): SmallTests identifies the modified functions from differences between two versions of source code and references the coverage information to find the corresponding tests.

This allows software developers to focus on the modified functions only. The number of required regression tests depends on the extent of changes made to the source code. In our experiment, SmallTests achieved an average of 30% fewer regression tests.

The method of analyzing code changes depends on the programming language. At present, SmallTests supports C/C++, Java, PHP, and Python. Because we offer SmallTests as a web service, there are no prerequisites for using the service.

1.38 Trials and Evaluations of Software Development Efficiency Improvement Using Generative AI



Generative AI use cases in software development

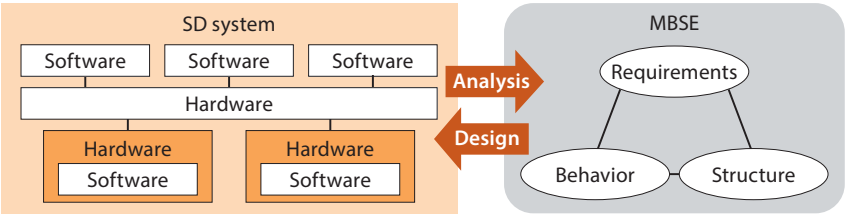
The Toshiba Group is conducting trials and evaluations of the use of generative AI in various software development tasks, aiming to build and deploy useful applications. So far, we have conducted trials and evaluations for various use cases, such as generating design documents and reviews in different stages of software development, including requirements definition, design, implementation, and testing.

Through these trials and evaluations, we have confirmed that using generative AI provides a 50 to 70% reduction in the time required to create documents and generate tests, compared to when human personnel create them from scratch.

We have also tried generative AI to develop a chat application that answers questions about software assets and proposes changes. The purpose of using generative AI is to utilize a vast amount of software assets to fix software bugs, add functional enhancements, and develop new product models. Our trials showed promising results in obtaining useful answers from a chat application.

We will employ generative AI for actual software product development projects for use cases where it has been proven useful. Based on evaluation results, we will promote technological improvement and deployment.

1.39 Development and Implementation of System Modeling Training Programs for Promoting Software-Defined Systems



Consistent analysis of system requirements, behavior, and structure based on MBSE makes it possible to design SD systems with configurations, performance, and functions that change according to the situation.

Relationship between SD systems and MBSE

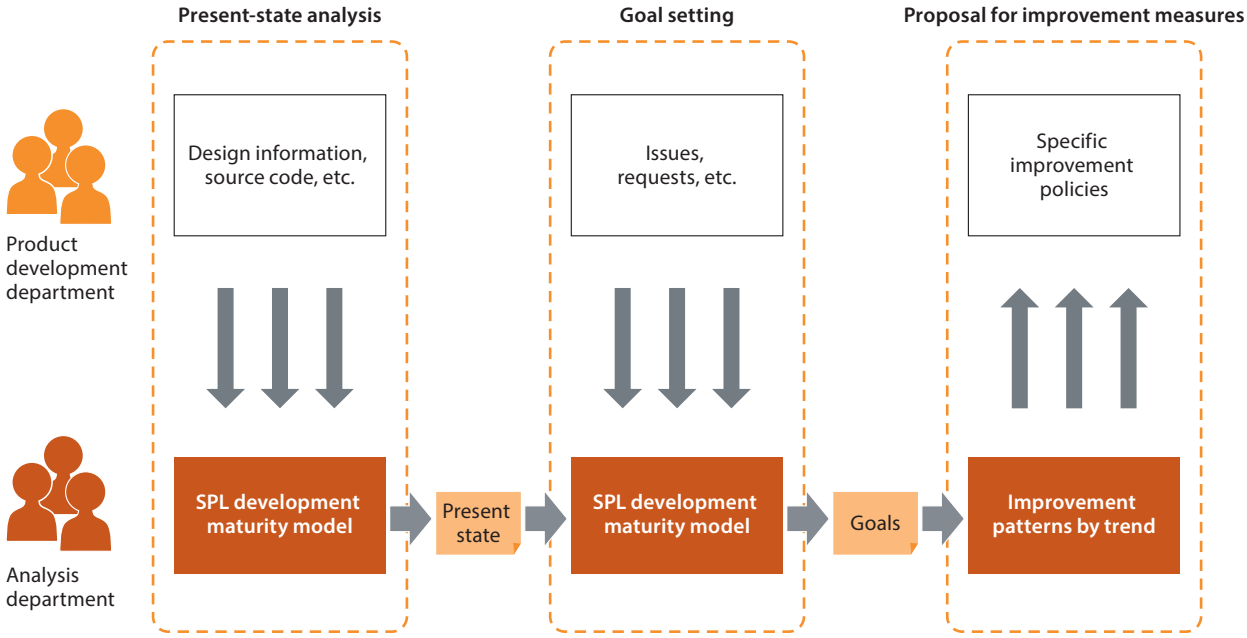
Stage	Audience	Description
Experience course	• Engineers who do not know what system models are • Engineers who do not know what SysML is	• Simple examples of partial system modeling • Lessons about what to code in system models
Introductory course	• Engineers who know what SysML is but do not know what to write in system models • Engineers who do not know how detailed system models should be	• Simple exercises to acquire basic modeling skills that require thinking about the type and what purposes given system models are necessary for, and how to code them
Practical course	• Engineers who know how to describe system models but find it difficult to model real systems • Engineers who want to use system models for work but do not know how to apply them specifically • Engineers who want to describe purpose-oriented system models	• Modeling of familiar systems to explain how they work to other people • Experiences in deepening understanding of systems, identifying unclear points, and resolving doubts through explanations using system models • Lessons to acclimatize engineers to creating practical system models

Intended participants and contents of the system modeling training program at each level

Model-based systems engineering (MBSE) is a well-known methodology that leverages models to efficiently manage the development of complex systems. System models are designed to define the constituent elements of a system and their relationships and behaviors. Application of MBSE is crucial to the Toshiba Group Software-Defined (SD) Transformation strategy because SD systems pose more complex challenges than traditional ones.

Advanced knowledge and skills are essential to create system models based on MBSE, so we developed an engineer training program, focusing on the systems modeling language (SysML) necessary to create system models and practice MBSE. We then offered the training program for our employees who were interested in MBSE and evaluated its effectiveness. We plan on utilizing the new training programs to promote MBSE and SD transformation.

1.40 SPL Development Maturity Model to Evaluate and Improve Activities for Software Product Lines



Overview of SPL development maturity model

Ad-hoc development of similar functions for a collection of related software products such as low-end and high-end versions tends to be inefficient. As a solution to this issue, Software Engineering Institute at Carnegie Mellon University in the United States took the initiative in the development of software product lines (SPLs), or software engineering methods to improve the efficiency of creating a collection of similar software products. However, SPLs require many organizational activities, making them generally difficult to implement.

The Toshiba Group has developed an SPL development maturity model for evaluating current SPL initiatives based on 38 criteria. This model makes it possible to identify strengths and weaknesses for each evaluation criterion and helps to formulate a policy for improving SPLs further.

At present, we are applying the SPL development maturity model to similar software products to improve development efficiency.