1. Research and Development

1.1 Capacitively Coupled DC-DC Converter for Highly Efficient and Ultracompact Power Electronics Systems

Power electronics converters are installed on renewable energy and energy storage systems for connection to a power grid. The output power density of the power electronics converter, which is defined as the output power divided by the volume of the converter, has increased over the past few decades.

Previously, the key to achieving high power density was to increase the performance of semiconductor devices. At present, however, passive components such as inductors and transformers are the limiting factors that determine the output power density of power electronics systems due to the progress of semiconductor technology.

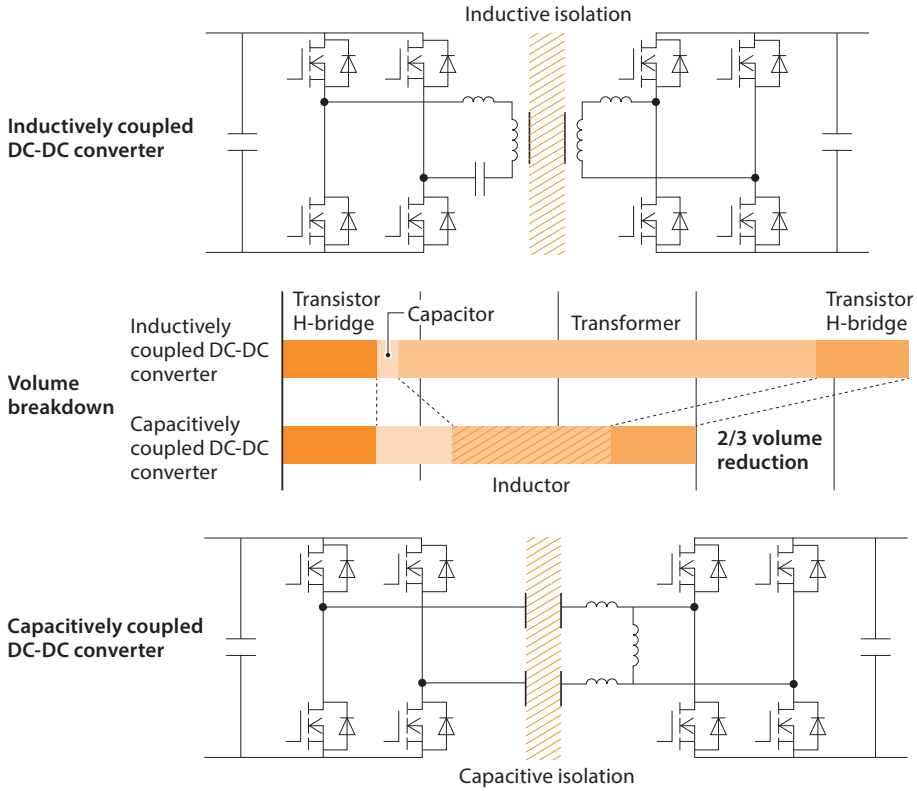
With this in mind, Toshiba Corporation has developed a capacitively coupled DC-DC converter to achieve a power electronics system with high power density. One of its features is galvanic isolation using series capacitors. A capacitively coupled DC-DC converter provides high power density because it is not equipped with bulky high-frequency transformers used in an isolated DC-DC converter (also known as an inductively coupled converter).

A single capacitively coupled DC-DC converter provides less flexibility than the inductively coupled DC-DC converter in terms of voltage transformation ratio because the former does not use transformer windings. However, a voltage transformation ratio can be programmed arbitrarily by connecting multiple capacitively coupled DC-DC converters in series-parallel. This is the second feature of the new converter.

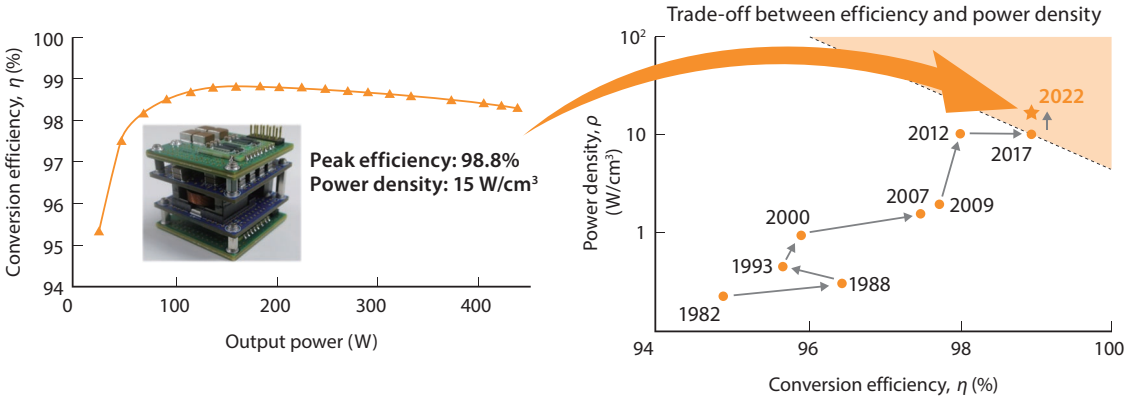
We have developed a 48 V–48 V, 450 W capacitively coupled DC-DC converter. An experiment confirmed that it provides a power density of 15 W/cm^3 (= 450 W / 30 cm^3) and a maximum efficiency of 98.8%. The power density of the current state-of-the-art inductively coupled converter is 10 W/cm^3 with a peak efficiency of 99%. This means that the capacitively coupled DC-DC converter provides 1.5 times higher power density while maintaining peak efficiency.

We have also demonstrated that a 48 V–384 V isolated DC-DC converter composed of eight series-parallel connected 48 V capacitively coupled DC-DC converters can be used to connect renewable energy and energy storage systems to a 380 V DC distribution system.

1. Research and Development

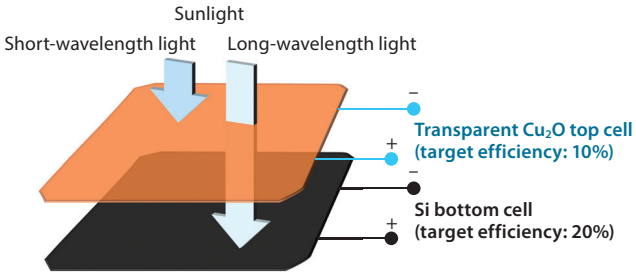


Capacitively coupled DC-DC converter achieving higher efficiency in a smaller size

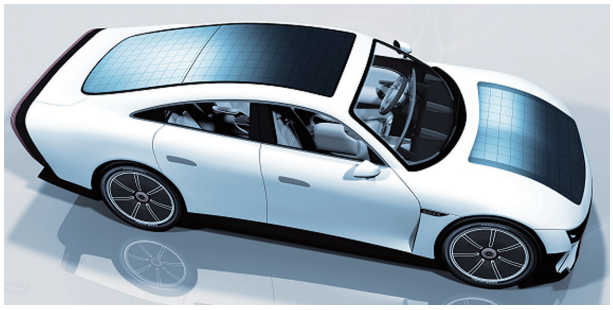


Results of 15 W/cm³ prototype capacitively coupled DC-DC converter demonstration

1.2 High-Efficiency, Low-Cost Tandem Solar Cell Using Cu_2O and Si



Schematic diagram showing the structure of a Cu_2O-Si tandem solar cell



Rendering of electric vehicle equipped with Cu_2O-Si tandem solar cells

Enlargement of a Cu_2O cell in development

To promote the widespread adoption of solar power throughout society, it is necessary to further increase efficiency and reduce the costs of solar cells.

Conventional high-efficiency solar cells include tandem solar cells in which III-V semiconductors such as gallium arsenide semiconductors are stacked using crystal growth technology. However, manufacturing costs are hundreds to thousands of times higher than those of crystalline silicon (Si) solar cells, making it difficult to use tandem solar cells in general applications.

In 2019, Toshiba Corporation developed a high-efficiency, low-cost tandem solar cell that consists of a transparent cuprous oxide (Cu_2O) solar cell and a crystalline Si cell. The substrate, material, and equipment costs of transparent Cu_2O solar cells are lower than those of III-V semiconductors.

1. Research and Development

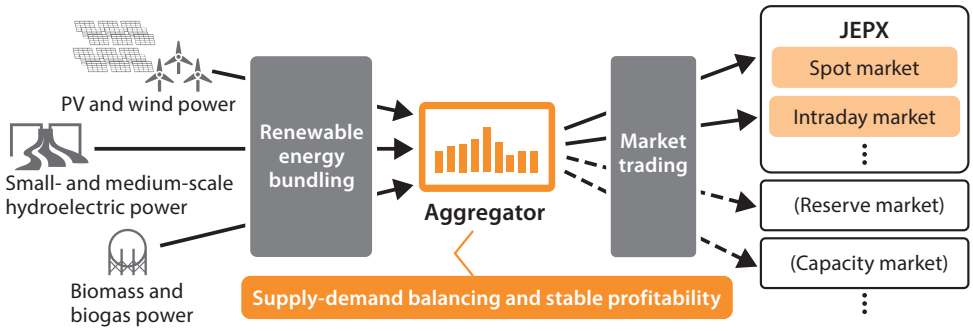
In September 2022, we succeeded in increasing the power conversion efficiency of a transparent Cu_2O solar cell (cell size: 10 × 3 mm) to 9.5%, the world's highest yet achieved for a Cu_2O cell (*). This broke the previous record we set in 2021, meaning that we are just 0.5 percentage points from our target. The newly developed Cu_2O tandem, which consists of a Cu_2O solar cell over a crystalline Si cell with a power conversion efficiency of 25%, is estimated to deliver a power conversion efficiency of 28.5%, which surpasses Si solar cells that are estimated to have an efficiency of around 26.8%. Our approach increases the amount of power that can be supplied, even with a limited footprint, and is expected to lead to electric vehicles (EVs) that run on solar energy without the need for recharging.

In the future, we will develop larger transparent Cu_2O solar cells for practical applications. In addition, we will work to further improve the efficiency of Cu_2O and Si tandem solar cells to a level suitable for rechargeable EVs and other electric mobility applications, thereby contributing to the realization of a carbon-neutral society.

Some of the results reported herein were achieved through research and development commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

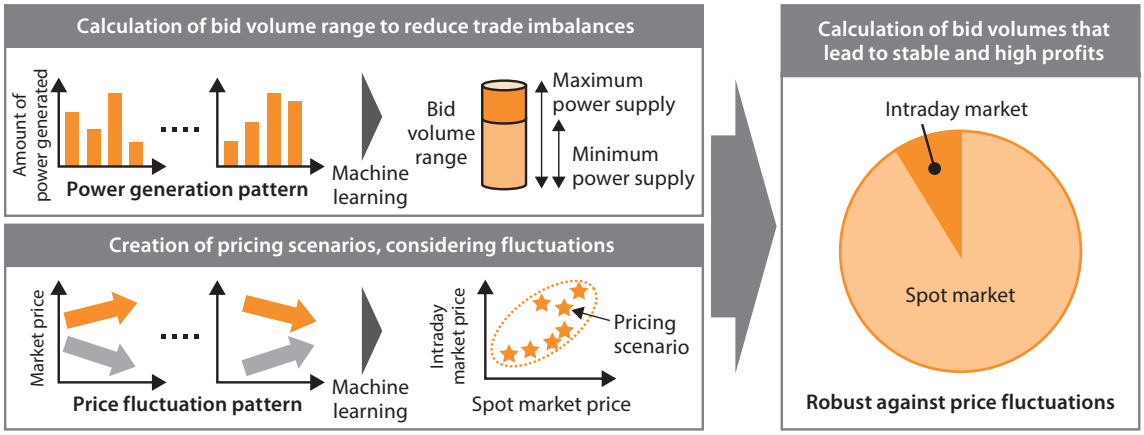
(*) As of September 2022 for Cu_2O solar cells (according to Toshiba Corporation research)

1.3 Technologies for Optimization of Renewable Energy Trading

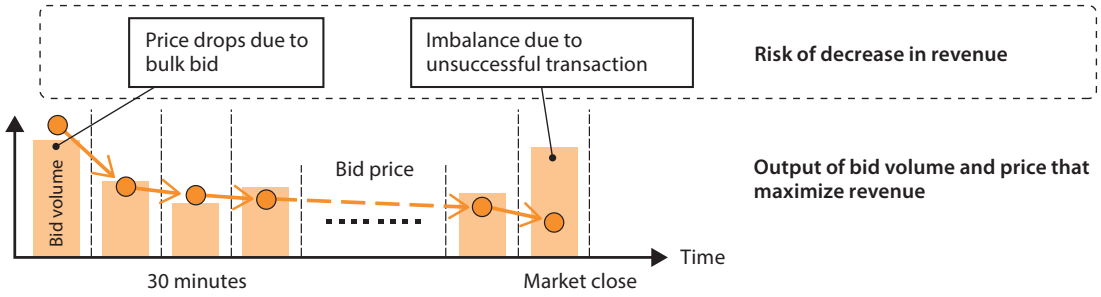


Overview of renewable energy aggregation service

Technology for trading on spot market



Technology for trading on intraday market



Spot market and intraday market trading technology

Renewable energy aggregation services generate profits through electricity trading markets and contribute to stabilizing the electricity supply. Toshiba Corporation has developed technologies to calculate the optimal bid volumes and prices to secure high profits while reducing the trade imbalance on the Japan Electric Power Exchange (JEPX) spot and intraday markets.

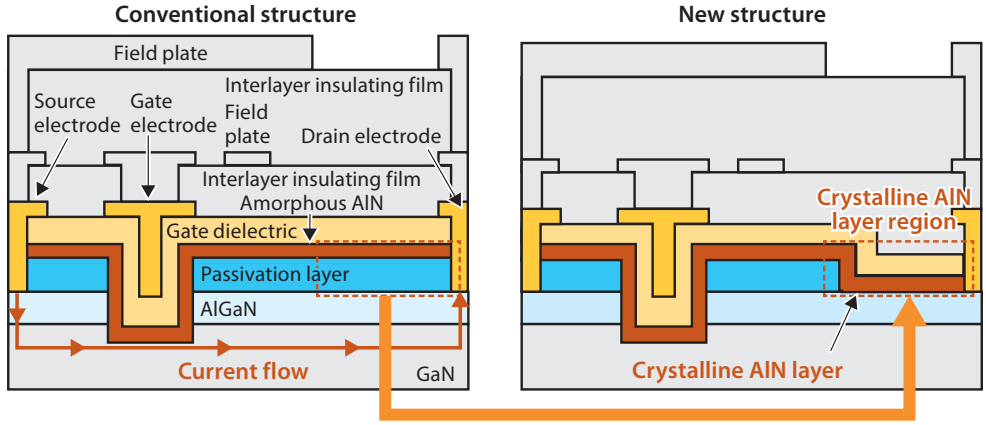
The technology for trading on the spot market uses machine learning and scenario optimization to reduce the risk of trade imbalances and calculate bids that will generate stable profitability.

1. Research and Development

The technology for trading on the intraday market calculates optimal bid volumes and prices at 30-minute intervals, considering the risk of a decrease in earnings. We have also developed a fast search method to find the optimal bidding procedure.

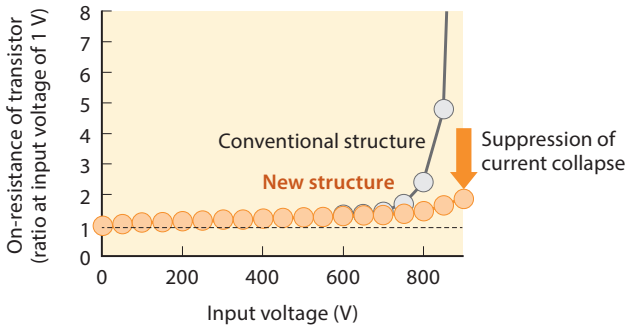
These technologies were used for the FY2021 and FY2022 Renewable Energy Aggregation Demonstration Projects at the Ministry of Economy, Trade and Industry (METI) of Japan and will be used for our renewable energy aggregation services.

1.4 Highly Reliable MOS Type GaN Power Transistor Through Application of Selective Single-Crystal Formation Method



AlGaN: aluminum gallium nitride

Cross-sectional structure of MOS type GaN power transistor



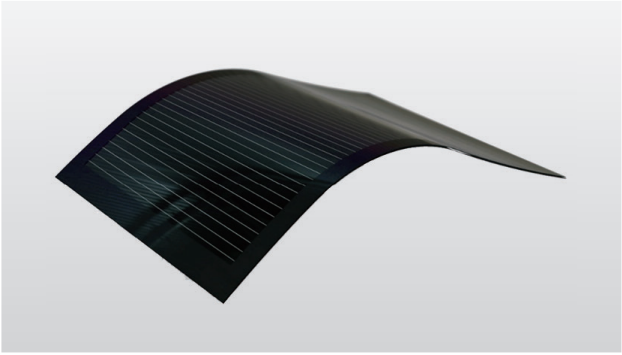
Comparison of on-resistance in conventional and new structures

Toshiba Corporation has created a prototype gallium nitride (GaN) power transistor with a new gate structure similar to that of a metal oxide semiconductor (MOS). Featuring stable on-resistance and a high degree of reliability, this GaN power transistor is expected to contribute to reducing energy consumption at data centers and in server power supplies. GaN power transistors exhibit current collapse, a phenomenon that causes a significant increase in on-resistance at high drain voltage. Because current collapse causes power loss and transistor failure, it is necessary to suppress it to achieve a high degree of reliability.

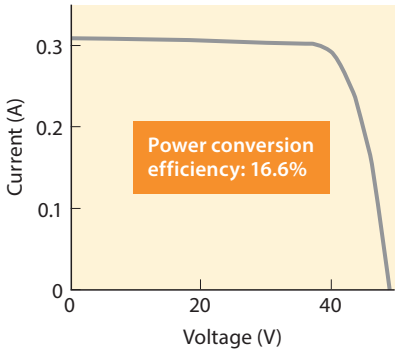
In order to elucidate the causes of current collapse, we analyzed the electrical characteristics of our GaN transistors. Based on the results of this analysis, we proposed and prototyped a novel device structure in which a high-quality single-crystal aluminum nitride (AlN) layer is formed as part of the transistor structure.

We confirmed that this structure reduces an increase in on-resistance due to current collapse by up to about 90% compared with the conventional structure. This result indicates that a highly reliable MOS type GaN power transistor can be achieved.

1.5 Film-Based Perovskite Photovoltaic Module with Enhanced Film Quality Achieving Improved Power Conversion Efficiency



Film-based perovskite photovoltaic module



Current-voltage curve of module achieving power conversion efficiency of 16.6%

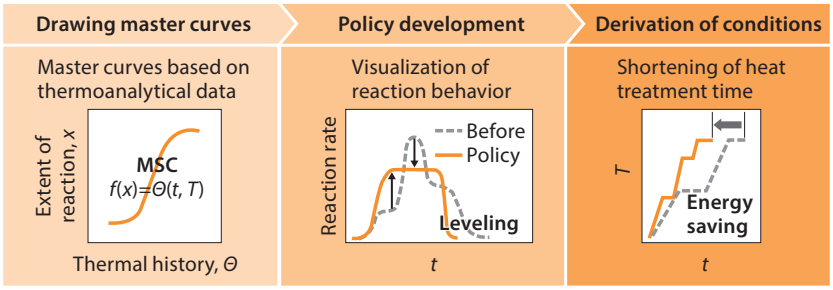
Film-based perovskite solar cells are lightweight, thin, and bendable. These features make them installable in locations with a limited load-bearing capacity such as factory roofs and building walls where conventional heavy crystalline Si solar cells cannot be used. To accommodate such installations, Toshiba Corporation has developed film-based perovskite solar cells to help expand renewable energy usage.

We have developed a one-step meniscus coating method capable of forming a perovskite film with a single application of one type of ink. Improvements to the one-step meniscus coating method coating and drying processes have resulted in enhanced film thickness uniformity and fewer perovskite film defects. This enables a film-based module with an area of 703 cm^2 with power conversion efficiency of 16.6% compared to 15.1% in the previous method, marking the world's highest efficiency for large film-based perovskite photovoltaic modules(*). The increase in power conversion efficiency has been achieved presumably because the improved film quality enhances charge extraction from the device.

The above was achieved in a project commissioned by NEDO of Japan.

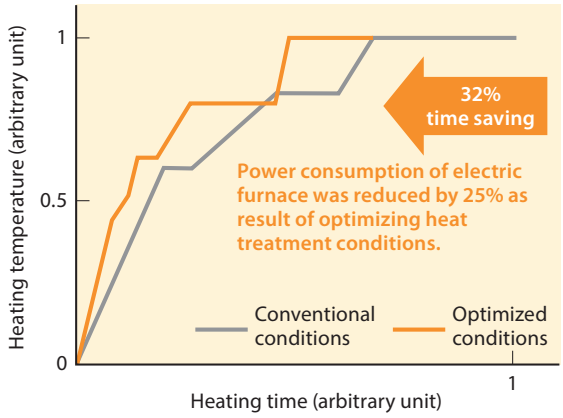
(*) As of October 2022 for 400 cm^2 or larger film-based perovskite photovoltaic modules with a plastic substrate (according to Toshiba Corporation research)

1.6 Heat Treatment Condition Optimization Technology to Reduce Power Consumption



t: heating time *T*: heating temperature

Electric furnace heat treatment conditions optimization process



Effect obtained by optimization of heat treatment conditions

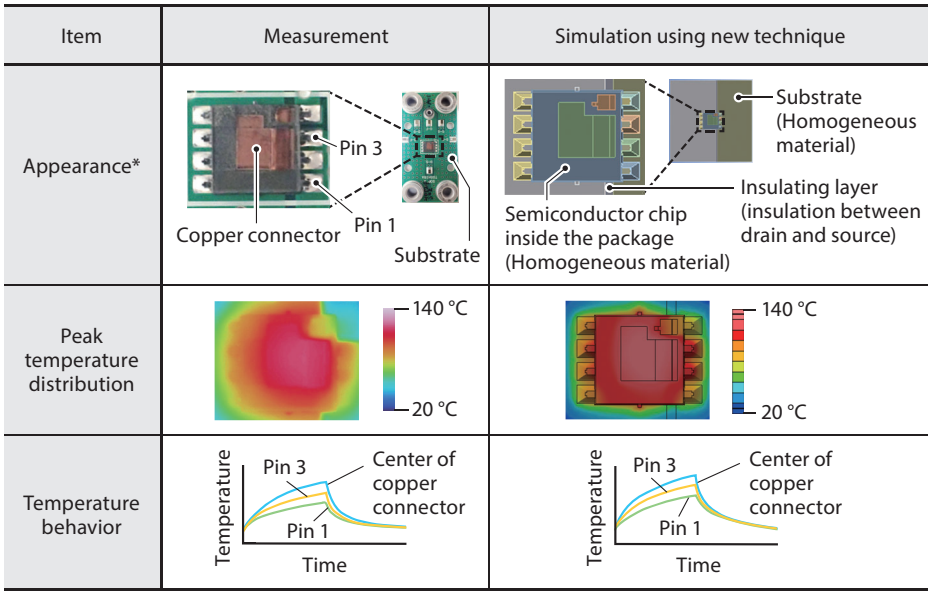
Heat treatment is a common process in the manufacturing industry used for firing metals and ceramics, curing resins, etc. Electric furnaces and other heating equipment employed for heat treatment processes consume the most electricity, accounting for 25% of the total power consumption in the manufacturing industry. This means that power consumption can be reduced considerably by improving the efficiency of heat treatment processes. However, conventionally, the manufacturing industry has often determined heat treatment conditions allowing large margins for heating temperature and time based on experience. Such conditions necessitated technology to optimize heat treatment conditions.

With this in mind, Toshiba Corporation has developed technology based on a master curve that represents the progress of chemical reactions and sintering over time. We have formulated the master curve by identifying the chemical reactions that occur during heat treatment and quantifying changes in physical quantities such as thermal reaction, mass, and thermal contraction through thermal analysis.

The new technology can combine a reaction rate analysis based on a master curve and a thermo-fluid analysis to visualize not only the temperature distribution in a furnace during heat treatment but also the progress of the reaction in the furnace, thereby making it possible to derive appropriate heat treatment conditions. We applied this technology to the ceramic product dewaxing process, achieving a 25% reduction in electric furnace power consumption while maintaining heat treatment quality.

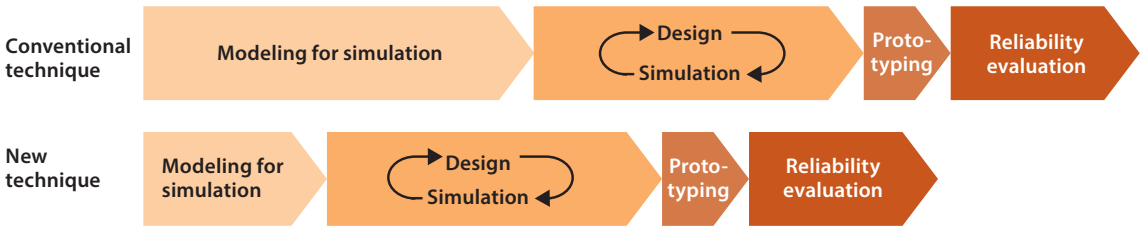
In the future, we will apply this technology to Toshiba Group product heat treatment processes to reduce power consumption and thereby contribute to achieving carbon neutrality.

1.7 Technique to Create Thermal Simulation Model for Early Prediction of Failure Risk for Power Semiconductors



* Internal structures of parts are exposed for evaluation purposes.

Comparison of measured and simulated temperature behavior during energization of semiconductor package



Shortening of lead time through application of technique to create thermal simulation model

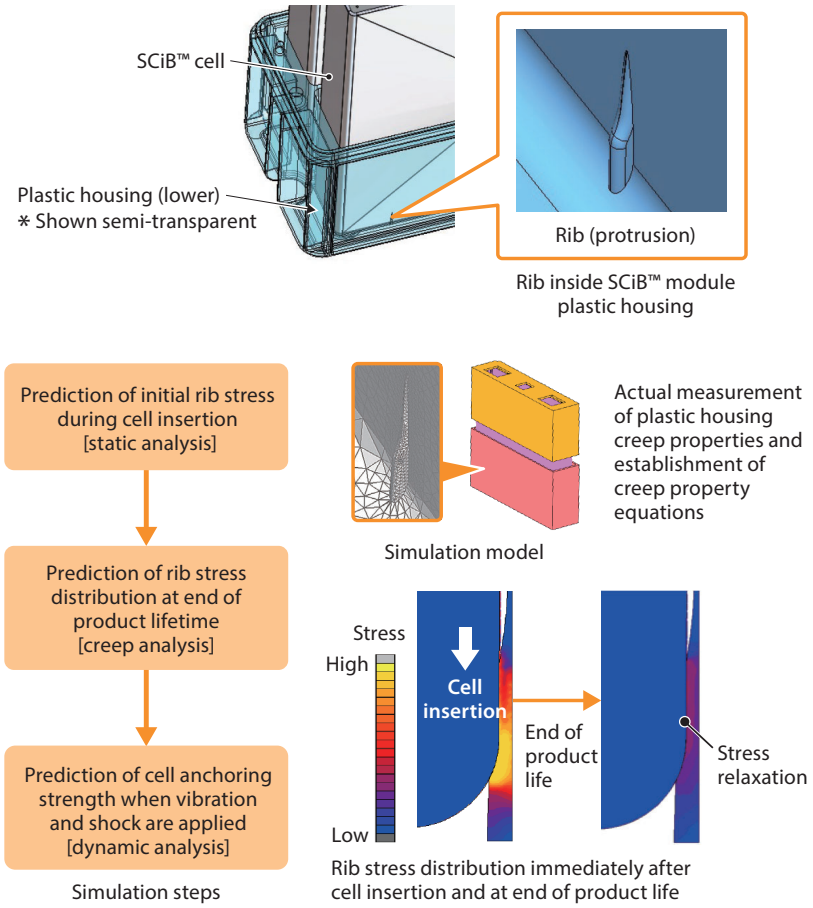
Power semiconductors are becoming progressively smaller while their current-handling capacity is increasing. As a result, there is growing concern over increasing device failures induced by thermal load. To ensure power semiconductor reliability, it is crucial to predict thermal loads during active operation at an early stage of the design cycle. The conventional approach to creating a thermal simulation model involves reproducing the complex internal structures of a semiconductor chip and substrate as well as the environmental conditions to which the substrate is exposed. However, this approach requires considerable time.

With this in mind, Toshiba Corporation has developed a new technique for creating a thermal simulation model capable of predicting the chip-to-ambient thermal characteristics considering the structures of the power semiconductor chip and the substrate as well as the heat dissipation paths during chip operation. The new technique models the temperature dependence of power semiconductor electrical resistivity based on their current-voltage characteristics while

modeling the thermal conductivity and heat capacity of the substrate's heat dissipation paths based on the measured transient heat.

The new technique makes it possible to predict thermal distribution and the effects of structural changes in a short period of time, enabling power semiconductor failure risk prediction while reducing the modeling lead time by approximately 80% without compromising model accuracy. Consequently, we can now enhance the reliability of power semiconductor products early at the design stage.

1.8 SCiB™ Cell Anchoring Technique to Reduce Environmental Impact of Manufacturing Process for SCiB™ Modules



Simulation technology to predict SCiB™ cell anchor strength at end of product lifetime

Toshiba Corporation manufactures SCiB™ lithium-ion rechargeable cells and SCiB™ modules that combine multiple SCiB™ cells, contributing to achieving a carbon-neutral society. In the manufacturing process of conventional SCiB™ modules, adhesives are used to anchor cells to a plastic housing, making it difficult to reduce manufacturing costs and environmental impact.

To resolve this issue, we have developed a technique to achieve stronger cell anchoring, which involves the use of ribs, or microscopic protrusions. Attached to the inside of the SCiB™ module plastic housing, ribs are compressed and deformed when a cell is inserted. We have also developed a simulation technology to predict cell anchoring strength at the end of the product lifetime, considering plastic housing creep properties, optimizing the rib shape in cooperation with the module design department.

1. Research and Development

We applied the new cell anchoring technique to an industrial SCiB™ module, succeeding in manufacturing a module that satisfies vibration and shock resistance requirements without using adhesives, contributing to reduced environmental impact. The standardized rib design has been applied to a new SCiB™ module, achieving the desired vibration and shock resistance performance, confirming the validity of the rib design. Mass production of the new SCiB™ module is scheduled to begin in 2023.

1.9 Palm-Sized High-Definition Solid-State Lidar Unit with Range of Up to 300 m

The applications of light detection and ranging (lidar)(*1), a three-dimensional (3D) laser ranging and imaging technique, are expected to grow to include autonomous driving and infrastructure monitoring. However, the two barriers to the widespread proliferation of lidar units are cost and size.

A lidar unit consists of a projector and receiver. The projector targets an object with a laser, and the receiver receives the light reflected from the object and calculates the distance to the object from the time required for the laser to travel to the object and back to the receiver. To achieve a small, high-performance lidar unit at low cost, the laser scanner mechanical parts (motors, mirrors, etc.) must be reduced in size while complying with the eye safety requirements of laser safety standards.

In 2021, Toshiba Corporation developed a first-generation prototype lidar unit that uses a two-dimensional (2D) light-receiving device to reduce the size of the laser scanner mechanical parts and the overall lidar system.

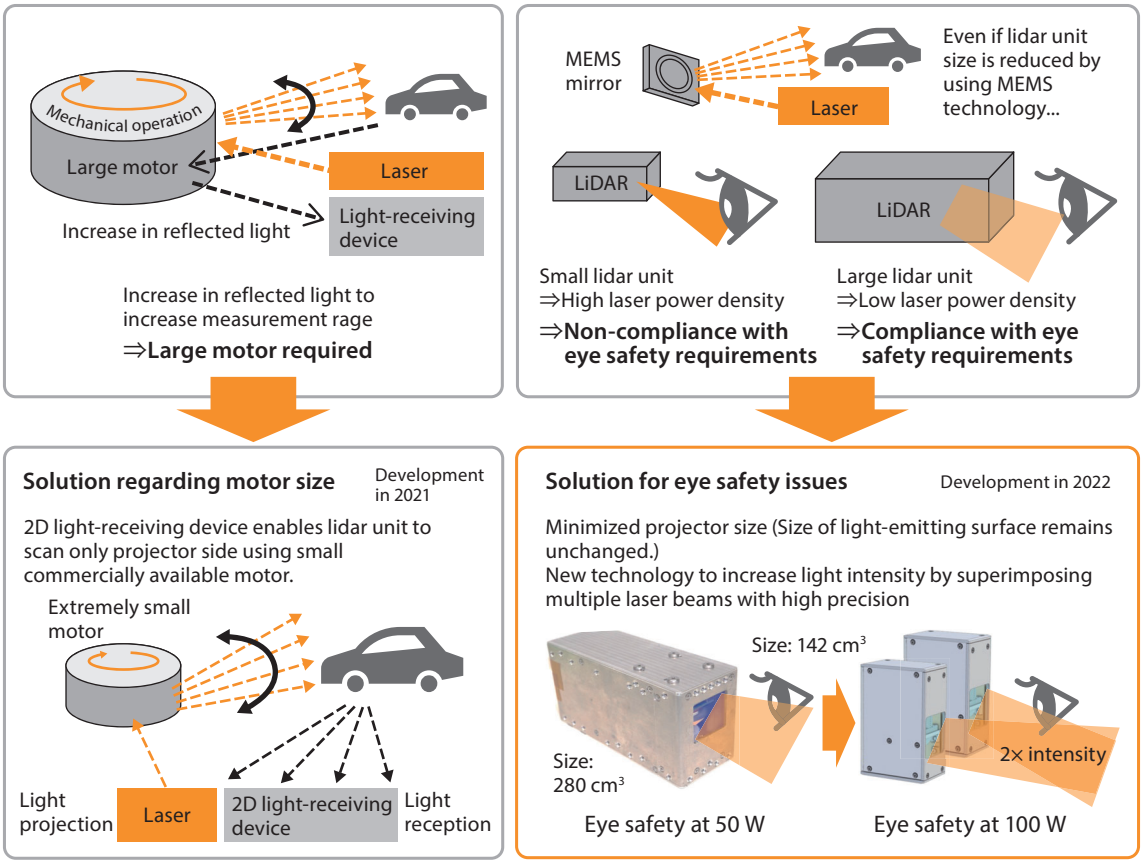
We have developed unique laser projection technology to increase laser intensity, thereby extending the measurement range. First, we employed 3D mounting technology to push the limit in reducing the size of the projector. We also incorporated multiple projectors into the second-generation prototype lidar unit and controlled the laser beam scan angle deviation to within 0.02 degrees. Laser beams from multiple projectors are superimposed to maintain sufficient light intensity over long distances while suppressing the light intensity of one projector to a safe level, even at close ranges, so as not to harm the retina.

The experiment demonstrated that the second-generation prototype lidar unit fires a higher intensity light at the target object than the first-generation prototype while complying with eye safety standards. Combining the projector and receiver technologies has resulted in a palm-sized lidar unit with a measurement range of 300 m and a resolution of 100 000 pixels, both of which are the world's top-class performance(*2).

We will continue to contribute to achieving a safe, secure society through the proliferation of lidar units and acceleration of autonomous driving.

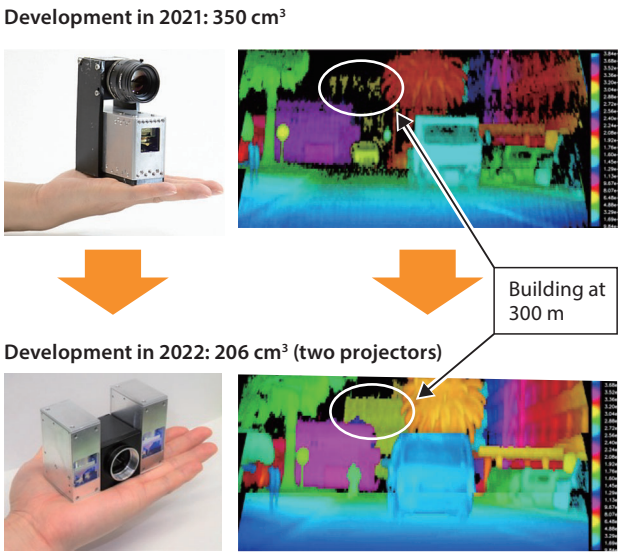
(*1) A technology that uses lasers to obtains information on the distance to an object as a 3D image

(*2) As of March 2022 (according to Toshiba Corporation research)



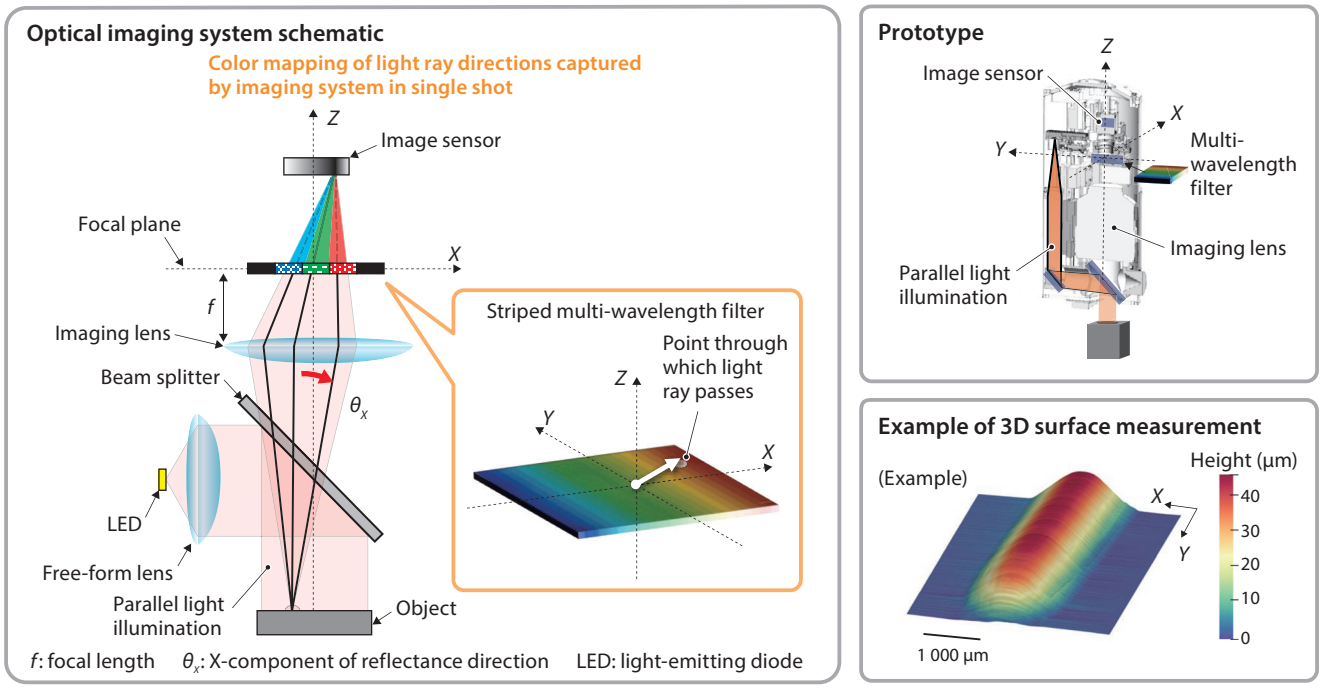
MEMS: microelectromechanical system

Improvements in light receiving and light projecting techniques for lidar units



Comparison of performance of first- and second-generation prototype lidar units

1.10 Optical Technology for Instantaneous Visualization and 3D Surface Measurement of Microdefects



Optical technology to visualize and measure 3D shapes of microdefects on product surfaces

In various manufacturing processes, optical measurement of product surface shapes is necessary for quality control. Non-contact methods are widely used to measure surface shapes via multiple images captured with conventional cameras. However, microdefects on a product surface, particularly those with height variations on the order of micrometers, are not clearly visible with conventional cameras because of low-contrast captured images. As a result, microdefects are often overlooked or measured inaccurately. Moreover, it is difficult to measure microdefects in real time without interrupting the manufacturing process or halting the production line.

To resolve this issue, Toshiba Corporation has developed an optical technology for 3D microdefect surface measurement, which uses an imaging system capable of capturing and representing the direction of light rays reflected from the surface as a color map. The new imaging system colors the light rays scattered by a microdefect differently than its surroundings, enabling clear visualization of the flaw. This imaging system can reconstruct the 3D surfaces of microdefects, even those with a height on the order of micrometers, from a single image. In an experiment using a prototype imaging system, we confirmed that it can accurately measure the 3D surface of an aluminum protrusion with a maximum height of around 10 μm within several tens of milliseconds at an accuracy of a few micrometers.

This technology is applicable to high-precision surface measurement of various microdefects, enabling identification during manufacturing processes. It also enables real-time measurement of the shape of metal melted during laser welding.

In the future, we will apply this technology to optical inspections in various manufacturing processes for accurate, fast product surface microdefect measurements.

1.11 Low-Power-Consumption MEMS Thermal Conductivity CO_2 Sensor for Indoor Air-Quality Monitoring

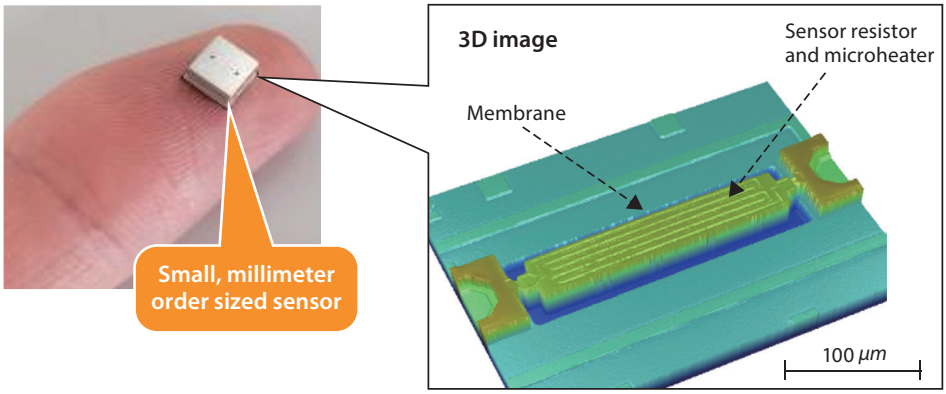
Indoor air-quality (IAQ) guidelines indicate that the indoor carbon dioxide (CO_2) level should be controlled below 1 000 ppm to avoid negative impact on the health, well-being, and productivity of the occupants. In addition, there is increasing demand for compact CO_2 sensors running on low power consumption that are easy to set up in order to assess the risk of COVID-19 and transmission of other infectious viruses, calculate carbon footprints, and visualize CO_2 emissions.

At present, conventional non-dispersive infrared (NDIR) CO_2 sensors are used to measure IAQ because of the high resolution. However, NDIR CO_2 sensors require several optical components and a high-power infrared source, making it difficult to reduce their size and power consumption. NDIR CO_2 sensors consume several tens of milliwatts.

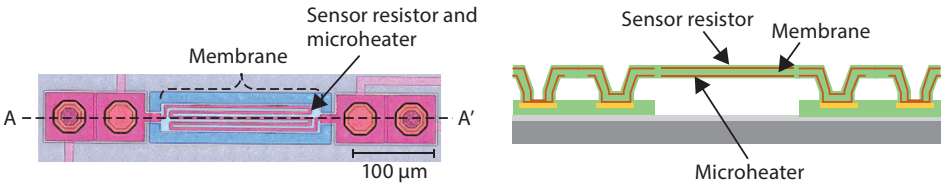
In contrast, thermal conductivity CO_2 sensors consume much less power and can be made smaller by applying microelectromechanical system (MEMS) technology. However, the resolution is currently insufficient for IAQ monitoring.

To resolve this issue, Toshiba Corporation has developed a prototype CO_2 sensor on a Si chip using MEMS technology, which has a membrane structure supported by highly thermally resistant anchors and springs. The new CO_2 sensor features a narrow air gap of a few micrometers between the membrane and the substrate as well as a microheater and a sensor resistor formed in the membrane. This CO_2 sensor heats the membrane with a microheater to measure the CO_2 level as a change in the thermal conductivity of the ambient air.

The thermal conductivity CO_2 sensor consumes much less power than the NDIR CO_2 sensor because the membrane is insulated by a highly thermally resistant spring and an air gap structure. The microheater and the sensor resistor are stacked vertically to reduce the size of the membrane and achieve high sensitivity sensing required for IAQ monitoring. The new CO_2 sensor provides a resolution of 61 ppm and consumes 1/40th the power of the NDIR CO_2 sensor because of intermittent operation. We will continue our efforts to achieve practical application of the new CO_2 sensor, including testing in an indoor environment.

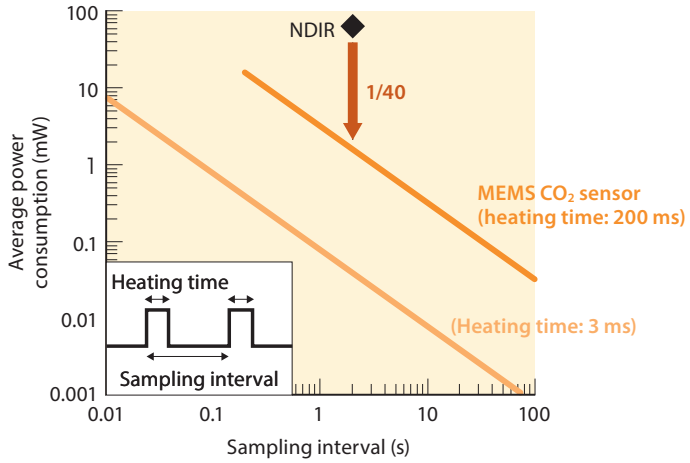


Prototype MEMS CO_2 sensor for indoor air-quality monitoring



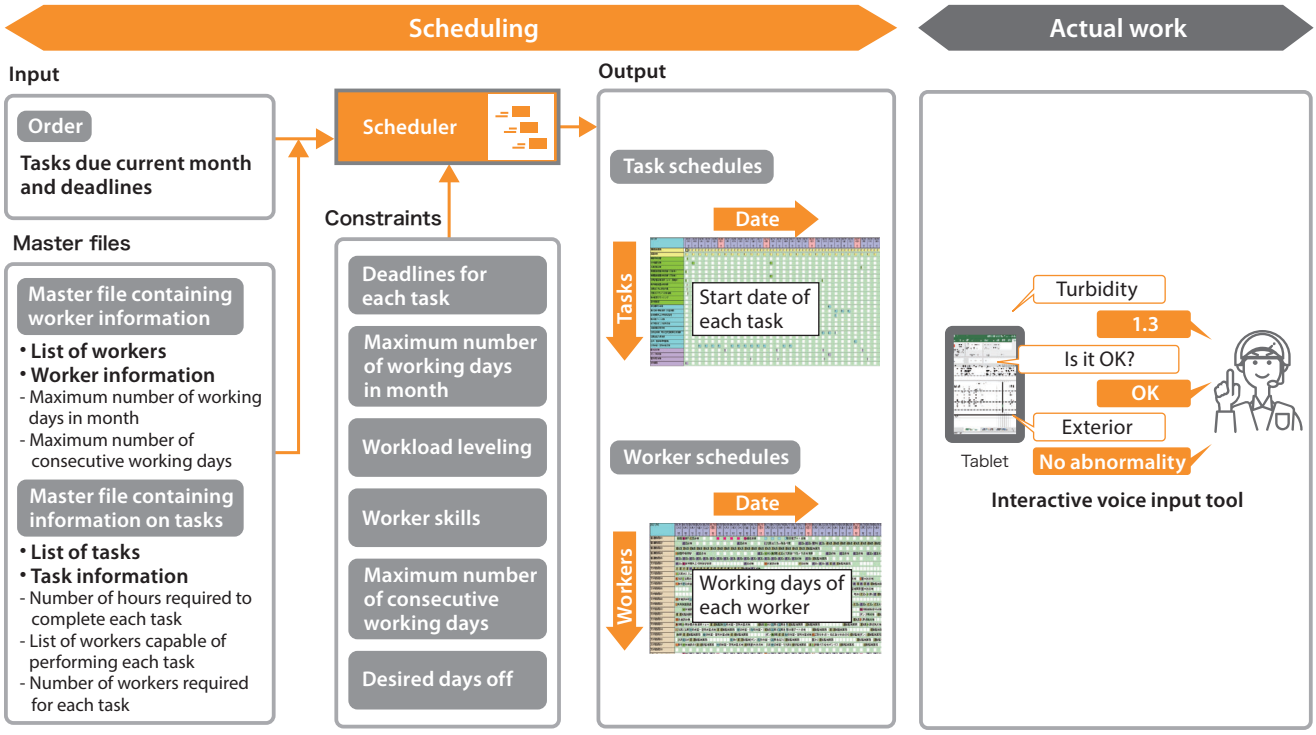
(a) Optical microscope image (b) Cross-sectional view of A-A′

Optical microscope image and cross-sectional structure of prototype MEMS CO_2 sensor



Comparison of average power consumption in conventional optical and MEMS CO_2 sensors

1.12 Scheduler and Interactive Voice Input Tool for Water Supply and Sewerage Facility Operation and Maintenance



Overview of scheduler and interactive voice input tool for water supply and sewerage facility operation and maintenance

For water supply and sewerage facilities operation and maintenance (O&M), it is essential to schedule workers who are knowledgeable about water treatment. Worker scheduling is necessary to ensure delivery of high-quality tap water and efficient treatment of sewage. However, scheduling can be time-consuming because of the need to consider various constraints specific to water supply and sewerage facilities. In addition, there are many parameters to be measured in periodic inspections and monitoring in order to control water quality. It is therefore desirable to streamline inspection and monitoring operation.

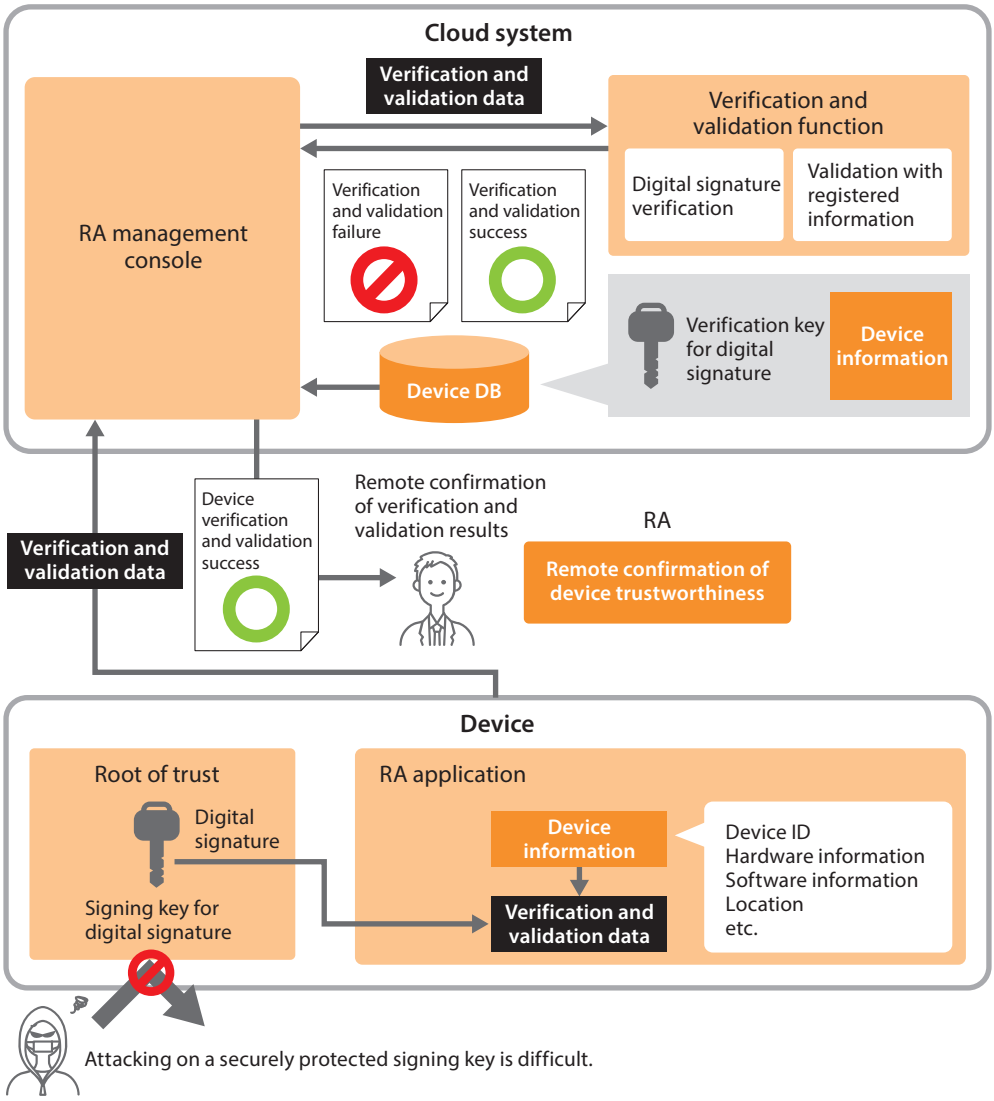
To meet this requirement, Toshiba Corporation has developed a scheduler for creating work schedules and an interactive voice input tool for hands-free inspection and measurement results recording.

A wide variety of tasks are required at water supply and sewerage facilities on a daily, weekly, and monthly basis. Work schedules must be created to meet these deadlines. In addition, various constraints such as worker skills, the maximum number of consecutive working days, and the workers' desired days off must be considered. The scheduler features an input format for tasks due during the current month and master formats for worker and task lists. It can generate work schedules that satisfy multiple constraints, thereby reducing the time required for scheduling.

The interactive voice input tool provides audio guidance on items to be inspected and measured in a predefined order. This tool makes it possible to standardize work procedures to prevent missed tasks, improve workability through efficient procedures and hands-free work, and reduce the time required for inspection and measurement work.

In the future, we will deploy these tools to water supply and sewerage facilities all over Japan to contribute to O&M efficiency.

1.13 Technology for Remote Detection of Cyberattacks Against IoT Devices



DB: database

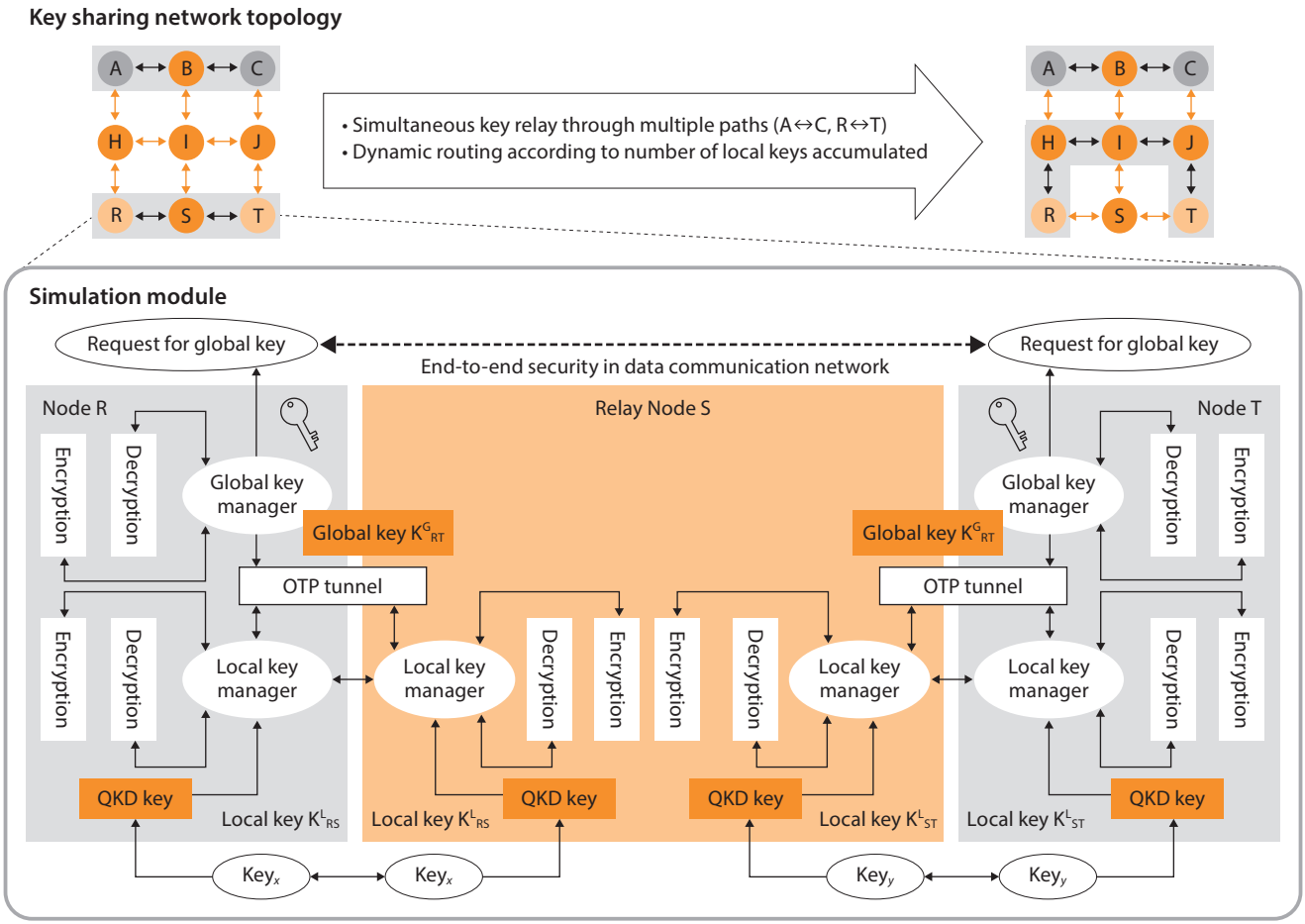
Outline of architecture for remote attestation

The number and variety of IoT devices have increased dramatically accompanying advances in cyber-physical systems (CPS). Data from IoT devices are collected and analyzed in the cloud to extract useful information and identify opportunities. However, because IoT devices are generally connected to the Internet, they are exposed to the increasing risk of cyberattacks. Because an IoT device that has been attacked can affect the behavior of the entire CPS, constant monitoring of IoT trustworthiness devices is necessary to ensure that they have not been attacked.

To meet this requirement, Toshiba Corporation has developed a remote attestation (RA) management function for HABANEROTS, its IoT platform service, which allows it to verify the authenticity and trustworthiness of connected IoT devices. The RA application on an IoT device encodes its status (including the device ID and an operation log) into tamper-resistant data using a device-specific key stored in a secure location such as a security chip and sends the encoded status data to the cloud when establishing a connection. The cloud then verifies the trustworthiness of the IoT device by searching the device status data for traces of cyberattacks. We have implemented the RA function in accordance with the Internet Engineering Task Force (IETF) Internet standards.

We will continue to improve detection accuracy to contribute to the establishment of secure CPS.

1.14 Simulation System for Evaluation and Verification of Large-Scale Quantum Key Distribution Network



K_{xy}: keys shared between node x and node y OTP: one-time pad
Key^L: Local keys (random numbers shared only between directly connected QKD modules)
Key^G: Global keys (other random numbers encrypted by OTP algorithm based on local keys)

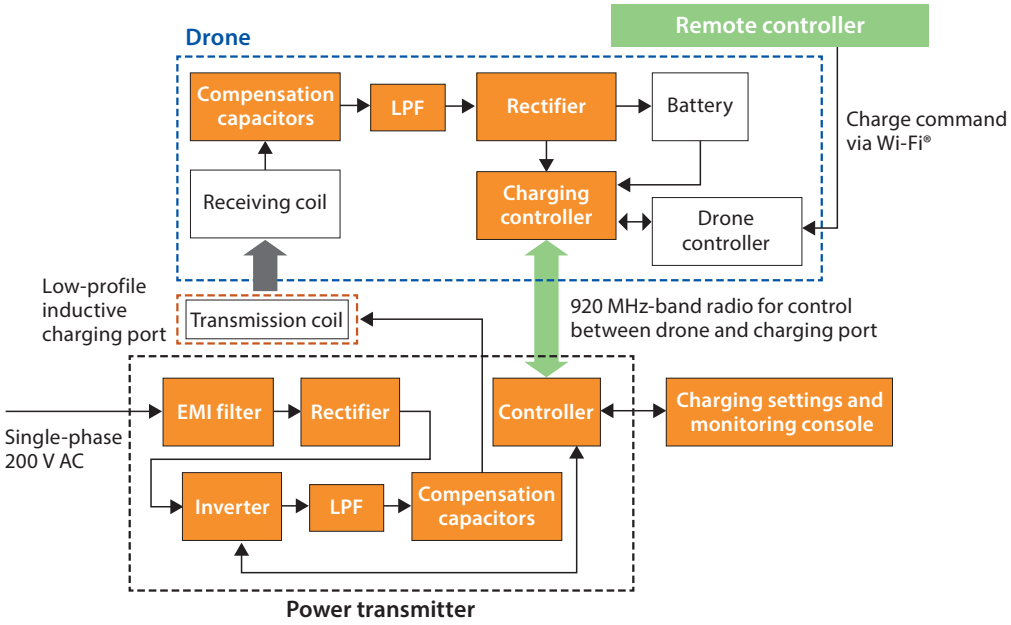
Overview of large-scale QKD network simulation

Quantum key distribution (QKD) is recognized as a major cryptographic solution that will support a future networked society. It is essential to expand the QKD network to make it available to a larger population.

With this in mind, Toshiba Corporation has developed a simulation system to evaluate and verify large-scale QKD network construction, control, and operation methods. The simulation system consists of modules for cryptographic key generation, key management, key relay, routing control, and cryptographic communication. It can evaluate the key generation speed on each link, simultaneous key relay through multiple paths, dynamic routing according to key accumulation status, etc., under programmed conditions. In addition, the simulation system visualizes simulation results. We built a QKD network with a grid topology consisting of 100 nodes and evaluated control and operations using the new simulation system.

Drawing on the evaluation results, we will continue with network control and operation technology R&D to further scale up QKD networks. Part of this project was conducted as R&D in the ICT Priority Technology Project (JPMI00316) for the Ministry of Internal Affairs and Communications (MIC) of Japan.

1.15 Automatic Wireless Drone Charger



LPF: lowpass filter EMI: electromagnetic interference

Block diagram of inductive drone charger

Low-profile inductive charging port and drone with wireless charger

Applications for medium-sized and large drones include the inspection of social infrastructure and delivery of goods. However, drones consume considerable electricity, necessitating frequent battery replacement and charging.

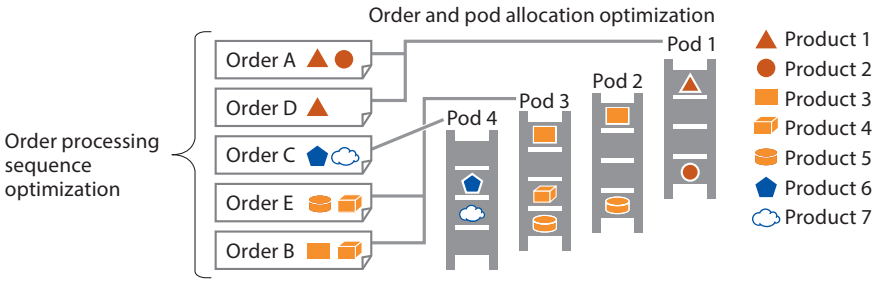
To address these issues, Toshiba Corporation and Toshiba Energy Systems & Solutions Corporation have developed a wireless drone charging port for automatic and unattended charging. A transmission coil that generates an 85 kHz alternating magnetic field is installed under a low-profile charging port with a height of 8 cm. The charging port leaves sufficient space for a drone to carry a camera or a parcel below the body. The receiving coil is housed in

the parking frame at the bottom of the drone. The current induced by the magnetic field of the receiving coil is rectified and charges the batteries. The structure on the rim of the charging port assists the drone in landing automatically at the designated position using the latest precision position detector. We successfully tested the most rapid 750 W and higher wireless charging(*), in-flight photography, and automatic landing.

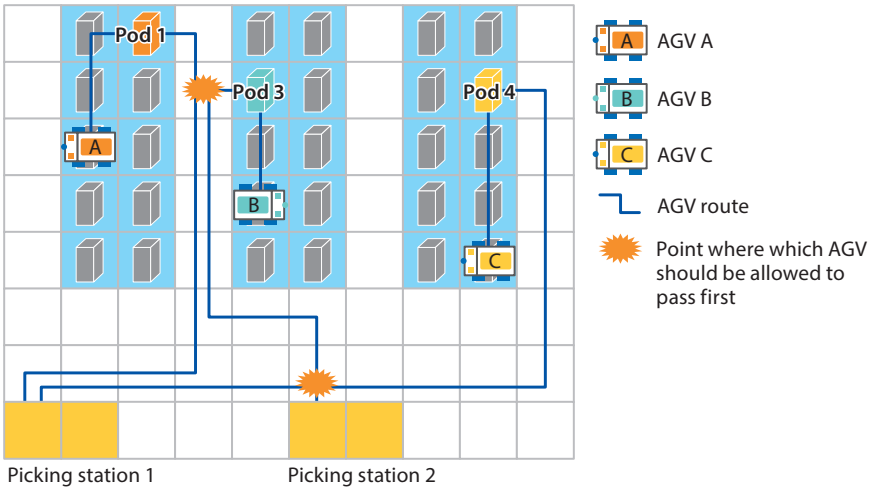
This project was funded by the Japan Science and Technology Agency (JST) and supported by the Council for Science, Technology and Innovation (CSTI) under the Cross-ministerial Strategic Innovation Promotion Program (SIP) for Energy Systems for an Internet-of-Energy (IoE) Society.

(*) As of November 2022 (according to Toshiba Corporation and Toshiba Energy Systems & Solutions Corporation research)

1.16 Technologies That Optimize Robotic Pod Transport Systems to Improve Throughput in Distribution Warehouse Operations



Optimized priority sequence of delivery orders



Example of shortest conflict-free AGV routings

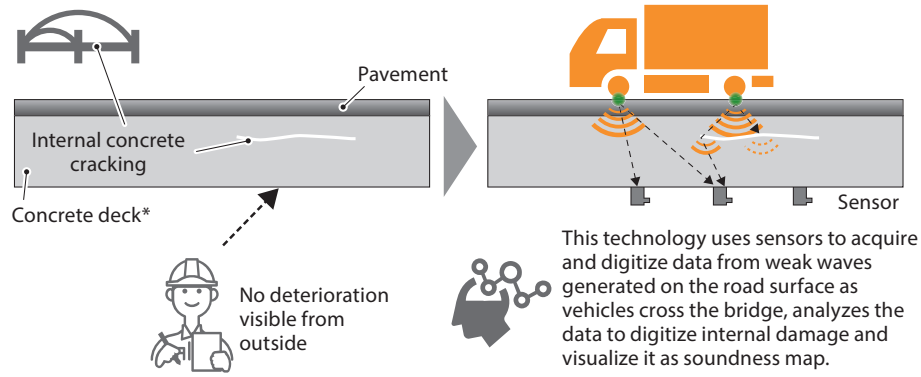
The robotic pod transport system at a distribution warehouse is designed to deliver pods loaded with products to a picking station using automated guided vehicles (AGVs). To maximize the throughput of distribution warehouse operations, Toshiba Corporation has developed two optimization engines which streamline the priority in which orders are processed, and the routes that AGVs travel.

The order prioritization engine prioritizes orders to maximize the number of products that are retrieved from the pods allocated to each order (hit rate). This is achieved by matching the pods containing the products listed on each shipping slip with picking stations. The AGV routing engine determines the travel route and timing of each AGV to minimize the total travel time while avoiding conflicts and deadlock. The optimization engines help maximize the throughput at distribution warehouse operations, i.e., the number of orders processed per unit time.

We built prototype optimization engines and incorporated them into a robotic pod transport system. We then emulated real-world conditions to compare the system's throughout with that of existing systems from other companies. As a result, we confirmed that our robotic pod transport system provides more than a 10% improvement in throughput.

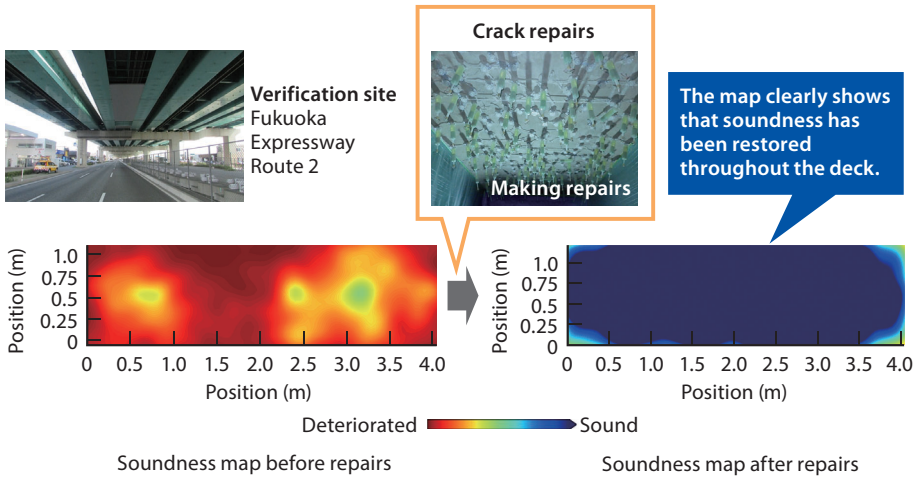
At present, we are installing the new system at a customer warehouse on a trial basis to evaluate performance and practicability.

1.17 Demonstration of Technology for Analyzing and Visualizing Internal Soundness of Bridge Decks at Fukuoka Expressway



* The part of the bridge that directly supports passing vehicles, constructed from concrete. These are generally used in bridges both in Japan and overseas.

Overview of technology for analyzing and visualizing bridge deck internal soundness



Visualization of bridge deck repair effectiveness

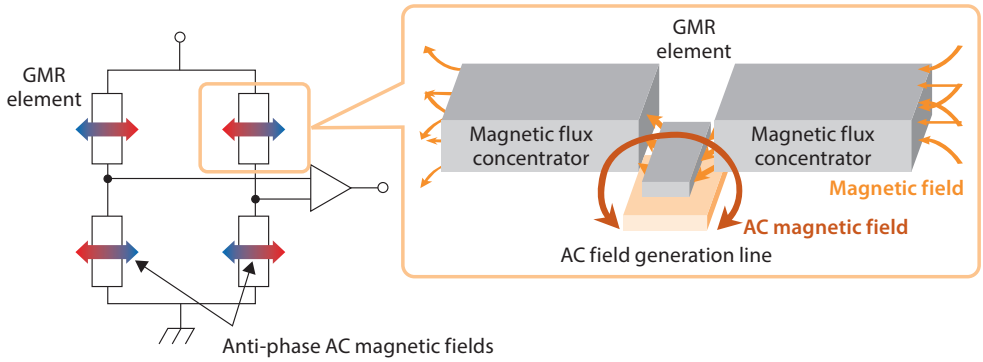
Toshiba Corporation has developed technology capable of analyzing and visualizing the internal soundness of bridge decks, demonstrating its effectiveness for expressway bridges. The technology uses sensors installed on the underside of the deck to acquire and digitize data from weak waves generated on the road surface as vehicles cross the bridge. It then analyzes the data to digitize internal damage that cannot be identified in conventional visual inspections for visualization as a soundness map.

We have demonstrated this technology during repairs to bridge decks on Fukuoka Expressway Route 2, confirming its validity in evaluating the internal condition of bridges by taking measurements before and after deck repairs. The technology will facilitate formulation of repair plans and task implementation according to the internal conditions of bridges, and further pro-

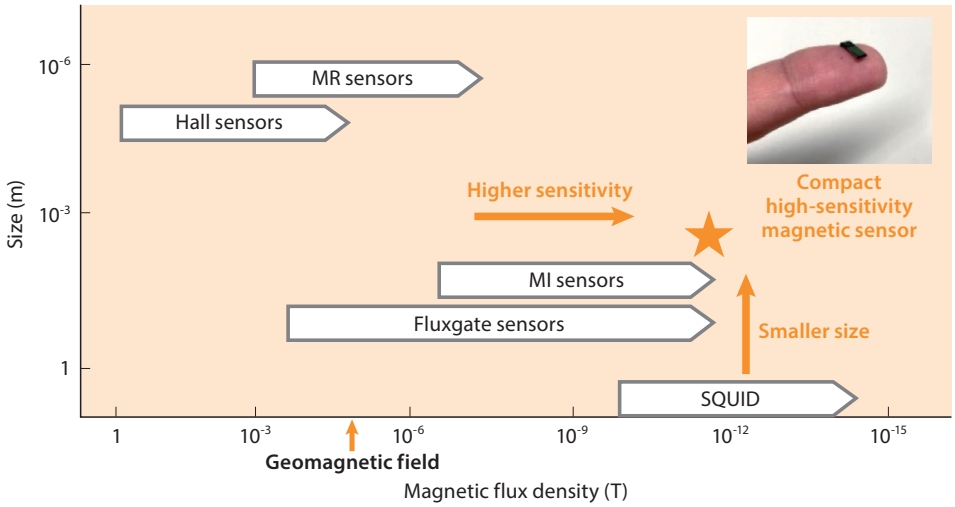
mote the digitalization of countermeasures against bridge aging, contributing to streamlined bridge repair and extended social infrastructure service life.

This new technology includes results from the "Robot and Sensor System Development Project for Infrastructure Maintenance and Disaster Surveys," a research project commissioned by NEDO.

1.18 Compact High-Sensitivity Magnetic Sensor



Overview of compact high-sensitivity magnetic sensor



MI: magnetoimpedance MR: magnetoresistance
SQUID: superconducting quantum interference device

Sizes and detection ranges for each type of magnetic sensor

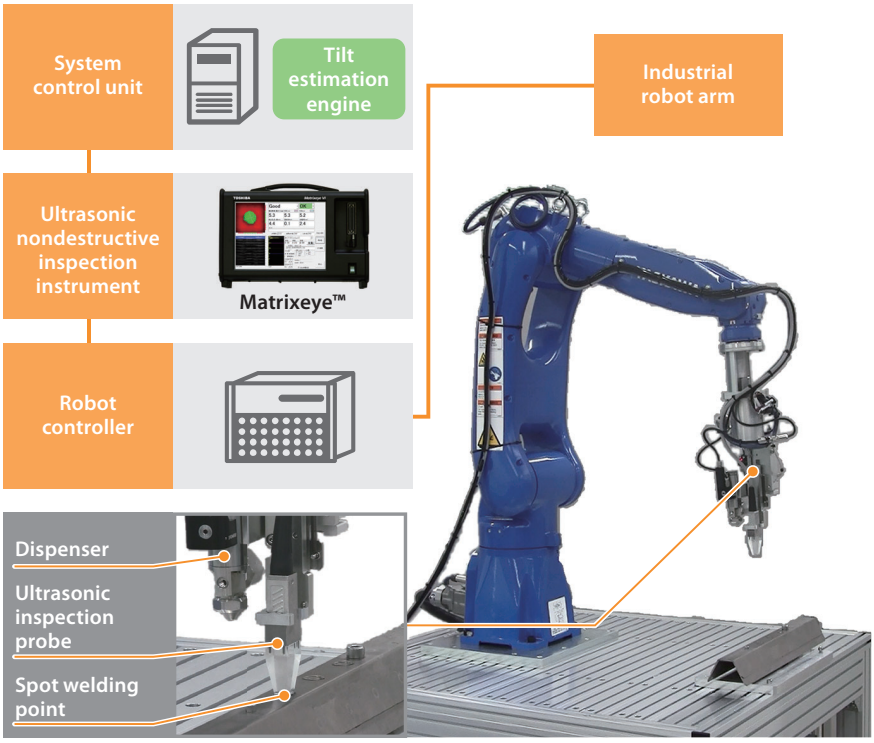
High-sensitivity magnetic sensors are attracting significant attention in applications such as nondestructive inspection of lithium-ion batteries and semiconductor chips. Magnetic sensors are used to sense weak magnetic fields generated by low leakage current. Although magnetic sensors must be small enough for use in inspection and IoT devices, there is a trade-off regarding the size and sensitivity of magnetic sensors. Until now it has been difficult for conventional magnetic sensors to meet both requirements.

With this in mind, Toshiba Corporation has developed a compact high-sensitivity magnetic sensor with a proprietary frequency modulation circuit, which uses a full bridge of four giant magnetoresistive (GMR) elements with a line capable of generating anti-phase AC magnetic fields. The new magnetic sensor can detect very weak magnetic fields due to reduced noise in the low-frequency region. Magnetic fields are amplified by a factor of about 100 using magnetic flux concentrators, which are then detected by GMR elements. As a result, the new

magnetic sensor has achieved detectivity of 8 pT/Hz (p: pico = 10^{-12}) at 10 Hz, which is $1/10^6$ of the geomagnetic field. Measuring only a few millimeters square, the new magnetic sensor is much smaller than other sensors with equivalent sensitivity, making it suitable for appliances requiring both small size and high sensitivity.

This work was supported by the Cabinet Office (CAO) SIP, “Intelligent Processing Infrastructure of Cyber and Physical Systems” (funding agency: NEDO).

1.19 Automatic Spot Weld Inspection System Enhancing Automobile Body Safety and Manufacturing Productivity



Automatic spot weld inspection system

Approximately 5 000 spot welds are performed to assemble the body of a single automobile. Conventionally, samples of car bodies were removed from the production line to inspect spot welds manually. This necessitates an efficient inspection technique that makes it possible to sample a sufficient number of inspection points to guarantee automobile safety while maintaining and improving productivity.

With this in mind, Toshiba Corporation has developed an automatic spot weld inspection system incorporating a tilt angle estimation engine(*1) linked to the Matrixeye™ ultrasonic inspection system that controls an industrial robot equipped with an inspection probe. The new spot weld system automates nondestructive inspection by measuring weld point diameters.

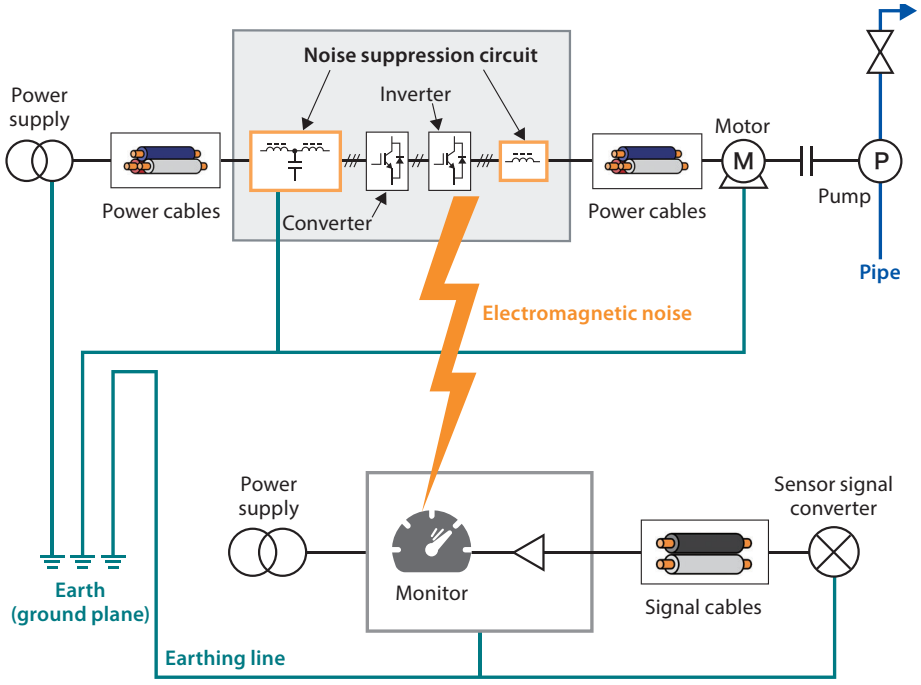
By running the software modules for weld diameter measurement and robot operation in parallel and optimizing the communication between them, the new system can inspect each weld in about three seconds. This is a considerable improvement in efficiency compared with a manual inspection that takes about 30 seconds per weld.

Following a test at a customer's plant, we received an order for the new inspection system in April 2022. We will continue to further improve the convenience of the system, for example, by eliminating the need of a couplant(*2).

(*1) Software that guides an inspection probe to an appropriate posture

(*2) An adhesive liquid that transmits ultrasonic waves to the test object

1.20 Design Technique to Predict and Reduce Electromagnetic Noise Prior to Installation of Large-Scale Systems



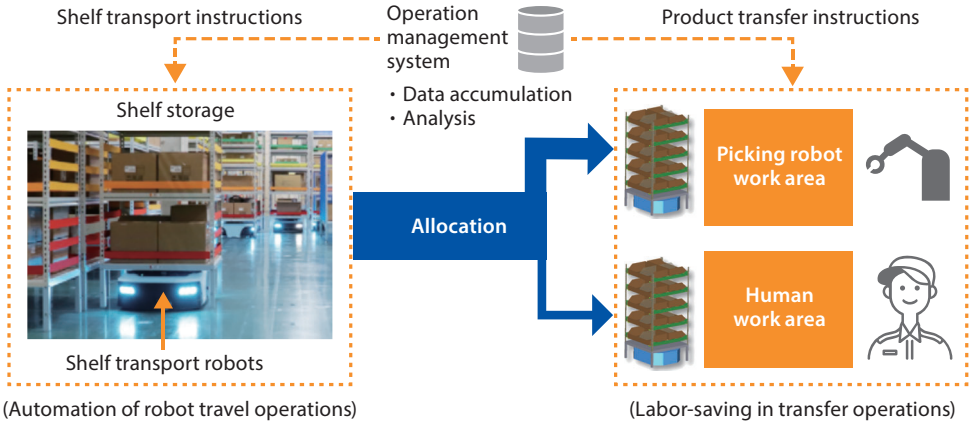
Configuration example of large-scale water supply and sewerage system applying electromagnetic noise design techniques

Large-scale systems such as water and sewerage facilities incorporate various electronic devices, including inverters for pump motors and sensors for monitoring system status. Depending on the combination and arrangement of electronic devices, electromagnetic noise that causes sensors to malfunction may become apparent after on-site system installation. Significant noise could also hinder the performance of a noise suppression circuit.

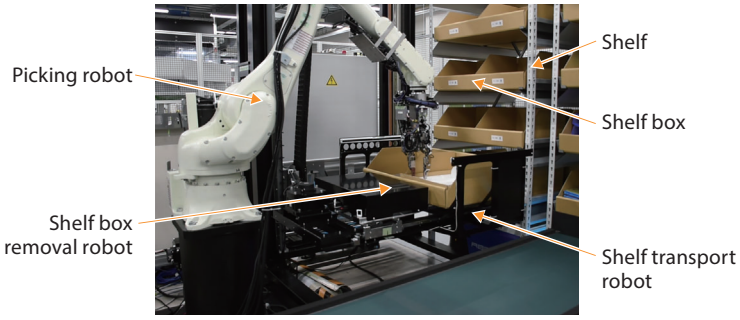
Therefore, Toshiba Corporation has developed a simulation technique to predict and prevent noise generation prior to system installation as well as a design technique for noise suppression circuits. The noise generated by an inverter propagates through noise suppression circuits, cables, the ground, and so on, affecting sensors and other devices. The new simulation model represents the noise propagation path as a parasitic component that is not shown in a circuit design diagram. This model has made it possible to quantitatively predict the amount of internal noise that could affect large-scale systems. Furthermore, we have identified the causes that could hinder the performance of a noise suppression circuit and developed a design technique to optimize it.

The combination of the new simulation model and design technique will help to reduce electromagnetic noise and shorten the time required for the commencement of system operations.

1.21 System for Worker and Robot Collaboration to Improve Efficiency of Picking Operations at Logistics Warehouses



Overview of labor-saving picking system operated through collaboration of workers and robots

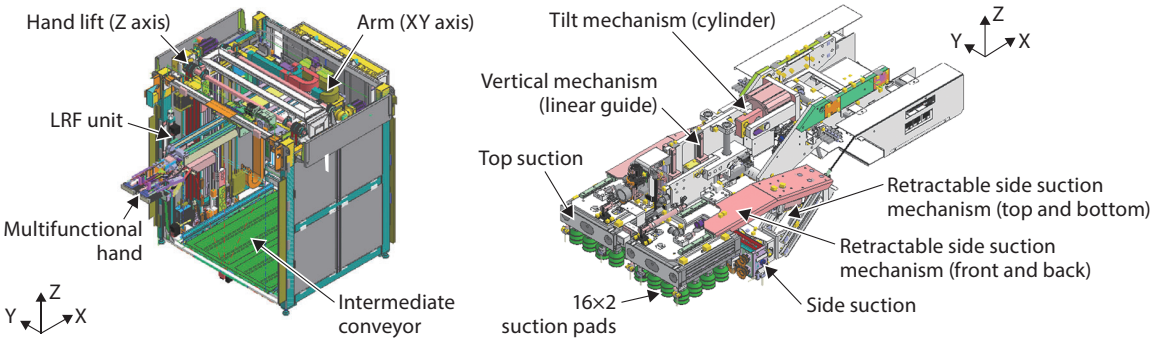


Picking operation in picking robot work area

At logistics warehouses, it is necessary to pick the designated products from a massive number of other products. In the face of labor shortages due to a declining working-age population, it is becoming increasingly important to save labor required in picking operations. A picking operation consists of traveling to the shelves where the target products are stored and removing them. While robots can easily be programmed to travel to the target shelves automatically, it is difficult for them to transfer various types of products from the shelves because of differences in shapes, materials, etc.

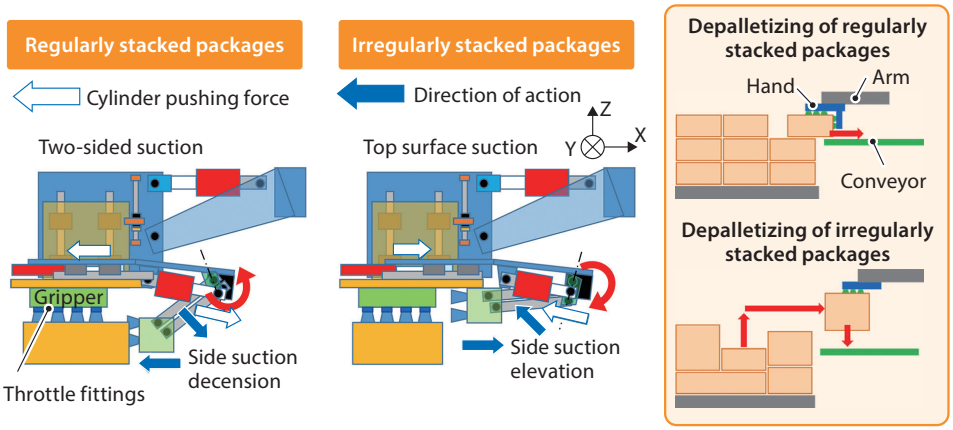
To resolve this issue, Toshiba Corporation has developed a system that allows a worker and multiple robots to collaborate in performing picking operations efficiently. In this system, a shelf transport robot transports movable shelves for automated robot travel operations, and a shelf box removal robot and a picking robot collaborate for automated product transfer operations. At the same time, an operation management system allocates products of sizes and shapes that cannot be handled by picking robots to human workers based on order information and pre-registered product attribute information. In this way, workers and robots share transfer operations optimally according to their capacities, thereby improving efficiency and saving labor in warehouse operations.

1.22 Depalletizing Robot Multifunctional Hand for Regularly and Irregularly Stacked Packages



LRF: Laser Range Finder

Depalletizing robot and multifunctional hand to accommodate both regularly and irregularly stacked packages



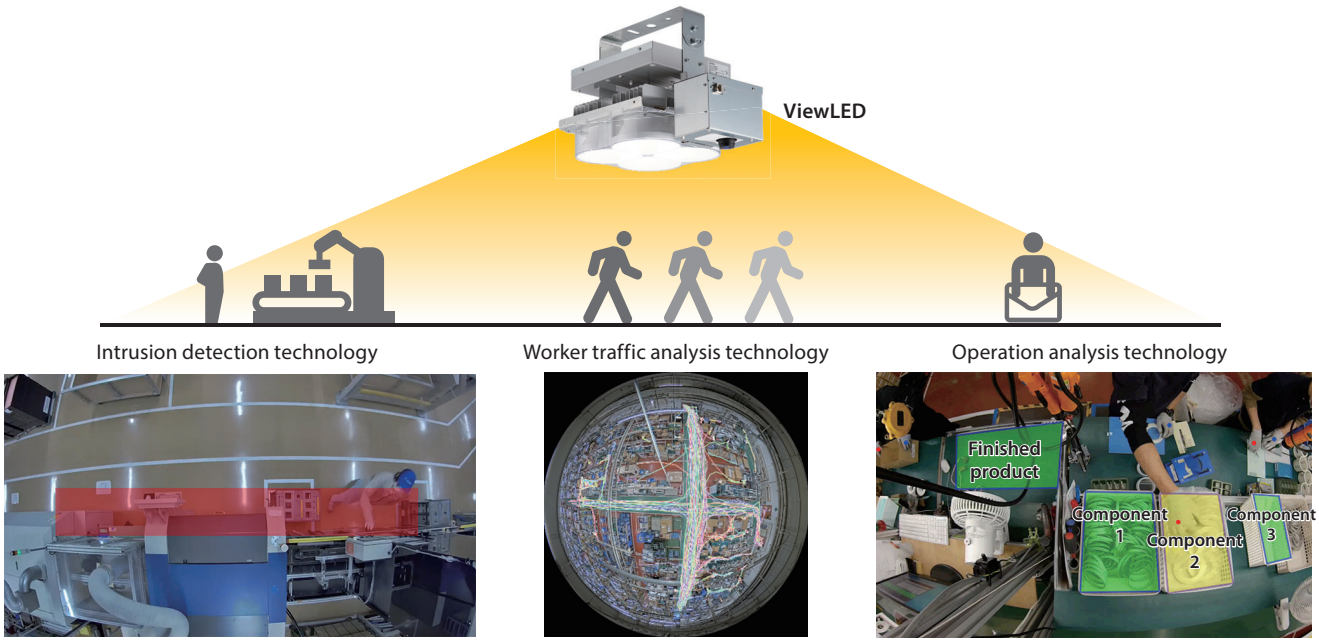
Schematic diagrams of retracting side suction mechanism

In recent years, the proliferation of e-commerce has led to a growing need for the automation of logistics tasks such as palletizing and depalletizing a wide variety of goods in warehouses. To solve this problem, Toshiba Infrastructure Systems & Solutions Corporation has released a depalletizing robot designed for regularly stacked packages of the same size.

Toshiba Corporation has now developed a multifunctional hand for robots that support both regularly and irregularly stacked packages of different sizes. This multifunctional hand can grab regularly stacked packages weighing up to 30 kg and irregularly stacked packages up to 20 kg. The retractable side suction mechanism allows the hand configuration to be changed according to packages to be depalletized. Regularly stacked packages are suctioned on the top and sides for depalletizing whereas irregularly stacked packages are suctioned only on the top because of the difficulty in accessing the sides.

In addition, upper suction uses 16 suction pads each on the left and right sides. The throttle fittings between the gripper and the suction pads ensure a certain level of suction force even if air leaks from some of the suction pads that are not placed on a package.

1.23 Video Analysis Using ViewLED Camera-Equipped Lighting Fixture Contributing to Improvement of Manufacturing Sites



Overview of video analysis technologies using ViewLED LED lighting fixture equipped with built-in video camera at manufacturing sites

Monitoring working conditions and identifying signs of potential accidents is effective for improving manufacturing site safety and productivity. Real-time monitoring of a whole factory helps achieve this purpose.

The ViewLED camera-equipped light fixture from Toshiba Lighting & Technology Corporation can replace existing lights and provides an easy way to visually monitor a factory. To help to improve safety and productivity, Toshiba Corporation has developed three technologies to analyze video images recorded by the ViewLED: intrusion detection, worker traffic analysis, and operation analysis technologies.

Intrusion detection technology is designed to improve factory safety. It detects human intrusion into dangerous areas on the factory floor. To warn workers of the hazards in machine surroundings, the technology identifies a machine's operating state via images and sounds an alarm if anyone approaches.

Worker traffic analysis technology is designed to improve factory productivity. It analyzes the worker traffic path vectors to reduce inefficient workflows. It not only keeps track of worker paths on the factory floor but also determines whether workers are pushing a trolley from the motion vectors around them. Lines of traffic can be visualized for each type of work.

Furthermore, the operation analysis technology is designed to analyze time spent at a workbench and work mistakes. It detects when workers extend their hands to grab a component. This information is used to measure the time taken to assemble a component and thereby plan

a more efficient process. Furthermore, this technology can be used to detect missed operations and issue an alarm in order to maintain operational quality. The operation analysis technology reduces analysis time by about 80% in comparison with viewing video and analyzing operation times manually.

We have incorporated all the new technologies into the ViewLED Solution, a cloud AI image analysis service from Toshiba Lighting & Technology Corporation. In the future, we will provide other video analysis services required at manufacturing sites to contribute to digital transformation (DX) initatives.

1.24 Quantum Communications Across Europe

Quantum key distribution (QKD) deployments and applications across Europe

Secure communication technologies are the backbone of today's digital economy. However, the emergence of quantum computers threatens to break the continued security of our communication systems. QKD solves this problem by distributing secret digital keys using quantum light.

Cambridge Research Laboratory (CRL) at Toshiba Europe Ltd. has demonstrated a wide range of QKD deployments across Europe, notably showcasing the seamless integration of QKD into existing network infrastructure. Such initiatives are important to demonstrate the readiness of QKD for bringing quantum-safe communications to existing networks, and our work in this regard has taken into consideration wide-ranging applications and novel QKD use cases.

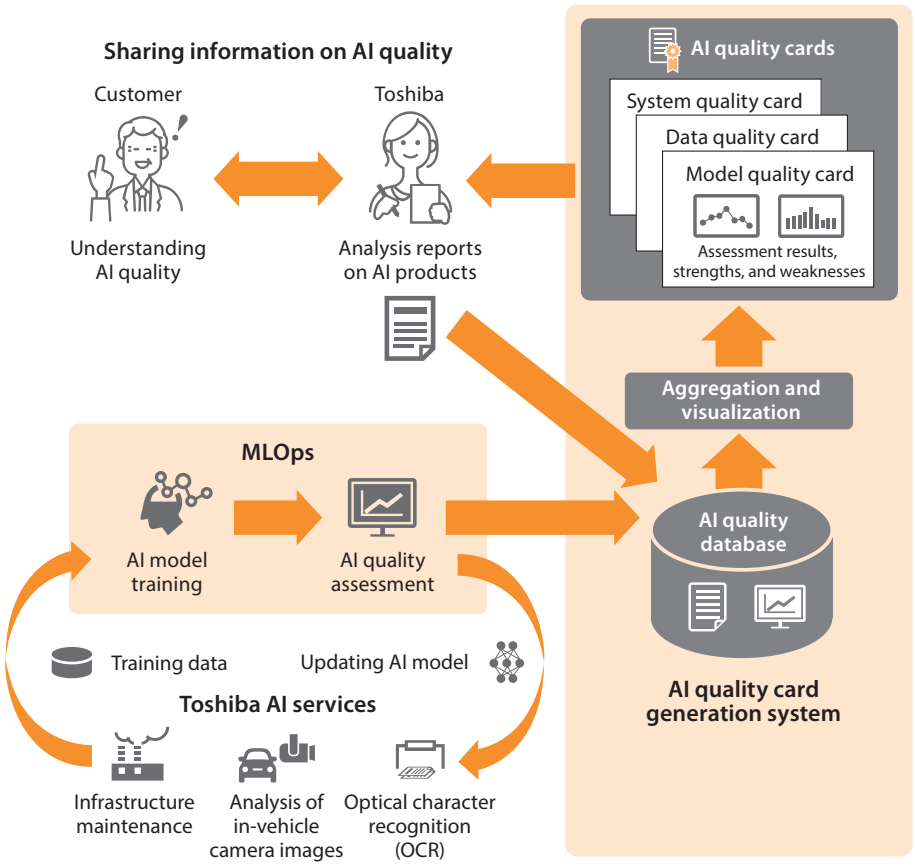
In Madrid, CRL has developed four QKD systems to secure a metropolitan network, including part of Telefonica's. One challenge of metropolitan networks is that optical fibers already carry significant conventional traffic, which can introduce noise when quantum light is added to the fiber. To circumvent this problem, CRL has developed advanced noise suppression technologies, which enable high-performance system operation, achieving multi-megabit per second secure bit rates. Similar metropolitan-scale (i.e., several tens of kilometers) fiber links were secured in Poznan and Graz, using quantum keys generated by CRL's QKD systems to seed commercial telecommunication encryptors running at up to 10 Gbit/s. Importantly, these links spanned critical infrastructure such as hospitals, and CRL demonstrated that QKD offers sufficient performance to support the transmission of highly confidential big data datasets such as medical images.

CRL deployed two QKD systems in Berlin to demonstrate integration of QKD with software-based post-quantum cryptography(*), which is another emerging technology for next-generation data protection. This was applied to protect the front-haul links of Deutsche Telekom's 5G network.

This project was partially funded by the European Union (EU) through the H2020 project, OpenQKD.

(*) Algorithms used to protect against attacks from quantum computers

1.25 AI Quality Card Generation System for Automatic AI Quality Visualization



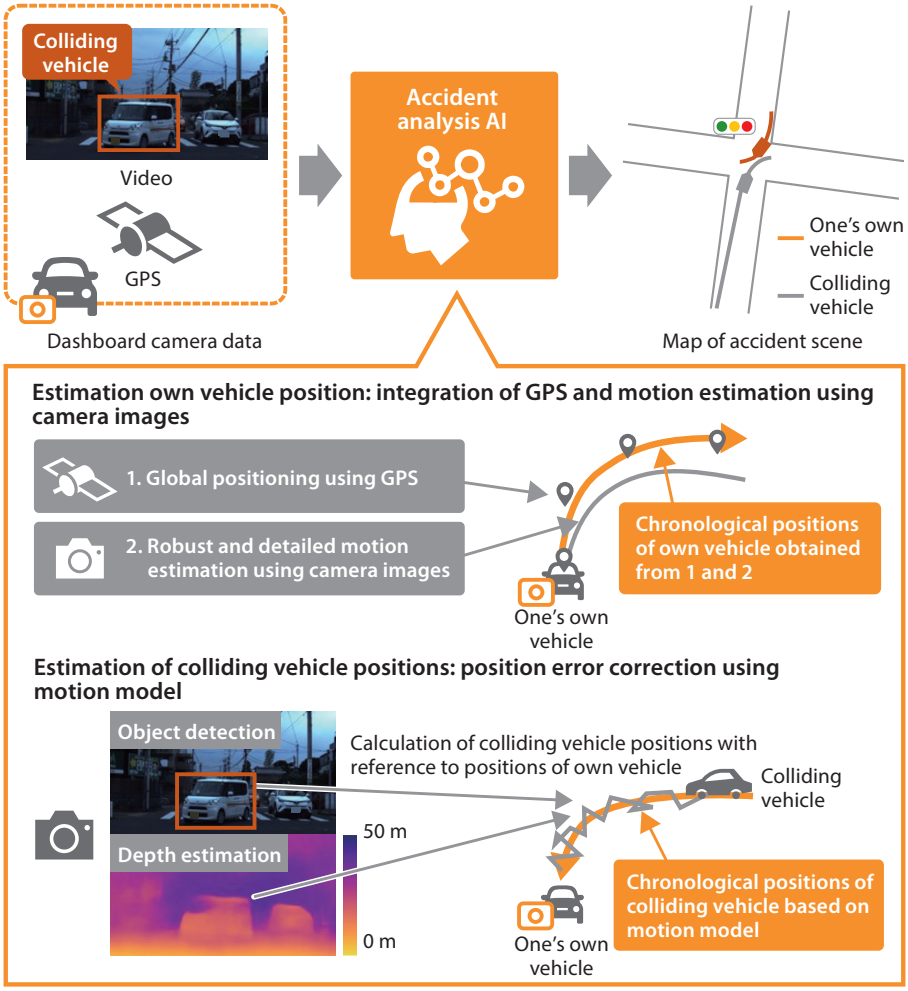
AI quality card generation system operating on machine learning operations (MLOps) platform

The behavior of products incorporating artificial intelligence (AI) cannot be precisely defined because AI model behavior depends on training data. In the case of an AI model that is trained using data collected during product operation, it is necessary to update information on AI quality each time it is re-trained. For example, AI quality information includes the results of quantitative evaluation and qualitative analysis. In order to help customers understand and be convinced of the AI quality, it is also necessary to visualize updated quality information in an easy-to-understand manner.

To resolve these issues, Toshiba Corporation has developed an AI quality card generation system that aggregates and visualizes quality information automatically. AI quality cards visually summarize quantitative and qualitative information and contain information on AI quality analysis results. The AI quality card generation system is designed to be able to operate on a machine learning operations (MLOps) platform(*) so that the cards can be kept up to date automatically. Sharing up-to-date information with customers via AI quality cards will help create trustworthy AI products.

(*) A framework for managing the lifecycle of an AI

1.26 AI Technology for Analysis of Vehicle Accidents Using Dashboard Camera Video



High-precision estimation of own vehicle location and collision object using accident video analysis AI technology

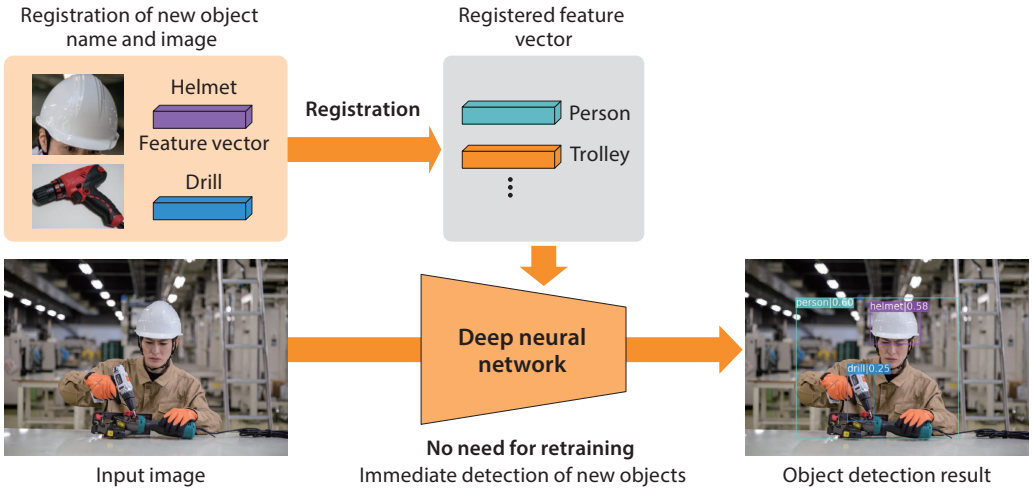
Modern dashboard cameras incorporate a global positioning system (GPS) and data communication functionality. When a vehicle collision occurs, the dashboard camera allows the driver to automatically send video and other data to an emergency service operator.

So that emergency service operators can understand how the traffic accident occurred, Toshiba Corporation has developed an accident video analysis AI, which generates a map of the accident scene showing a plot of the positions of one's own and colliding vehicles chronologically.

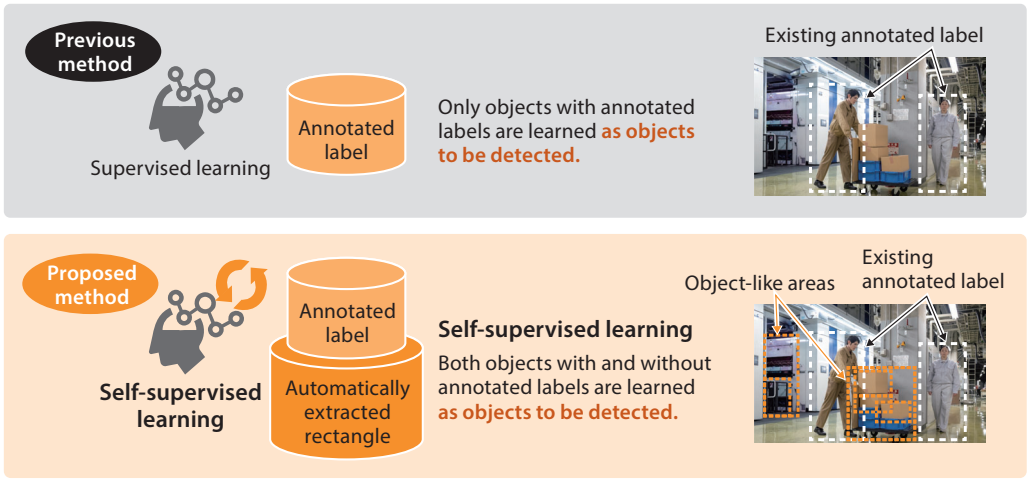
To achieve the application, accurate data on the positions (latitude and longitude) of one's own and colliding vehicles are required. For accurate positioning of one's own vehicle, we have developed a technique that combines global positioning using a GPS and robust, detailed motion estimation using camera images. For accurate positioning of the colliding vehicle, we have developed a technique that estimates its relative positions from camera images using

object detection and depth estimation. This technique then corrects position errors using a motion model based on a deep neural network. These two techniques make it possible to generate a map of the accident scene using a commercially available dashboard camera. We have confirmed that the positions of one's own and colliding vehicles are estimated with an error of 2.6 m and 3.0 m respectively.

1.27 Few-Shot Object Detection Technology Using Feature Vector Registration for Highly Accurate Detection of New Objects without Retraining



Overview of few-shot object detection technology for immediately adapting to new object from single registered image

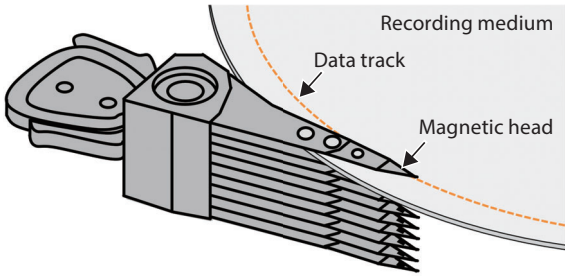


Introduction of mechanism to automatically learn various objects in images

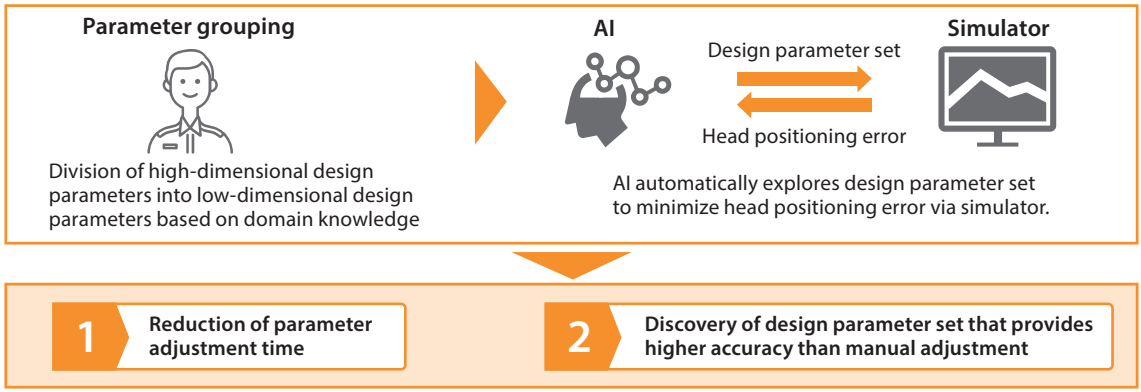
Object detection is an essential technology widely used in various fields to recognize human behaviors and surrounding environments. Generally, an object detection system is designed to recognize one or more specific objects in images. However, in actual environments, the need often arises to detect new objects for analysis after an object detection system is introduced. For the object detection system to recognize new objects, it is generally necessary to prepare a large number of training images to retrain a deep neural network. This makes it difficult to utilize an object detection system in environments where new objects frequently appear.

To resolve this issue, Toshiba Corporation has developed a new few-shot object detection technology capable of detecting new objects simply by registering a single image. This technology registers the feature vectors of new objects derived from a pre-trained network and detects similarities in feature vectors between input images to identify new objects. We have combined the new technology with self-supervised learning to learn the appearances of both the target and non-target objects in images during pre-training. As a result, we have succeeded in increasing object detection accuracy from 21.2% to 46.0%. This method will enable digitization in environments where AI has not been implemented before.

1.28 High-Dimensional Design Parameter Optimization for HDD Servo Systems



Outline of HDD head positioning control



Effects of applying high-dimensional design parameter optimization technology on HDD servo systems

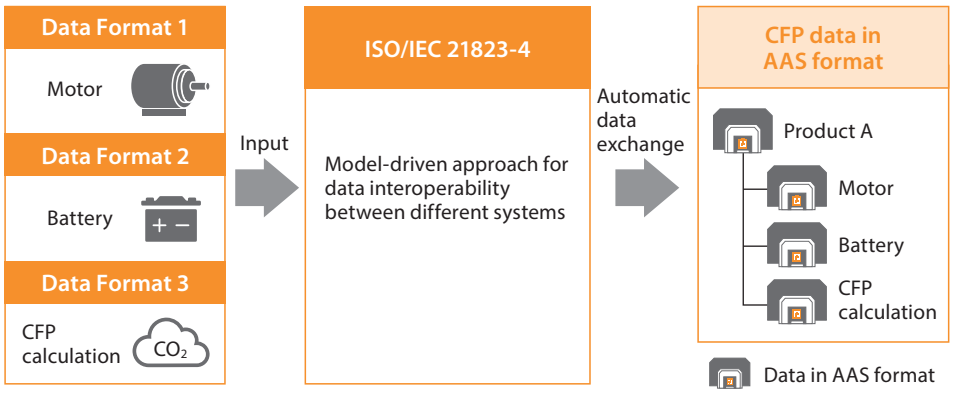
Brisk demand for high-capacity hard disk drives (HDDs) at data centers is driving the need to further increase recording density, requiring improvements in HDD head positioning accuracy. Under these circumstances, HDD servo systems to control head positioning are becoming increasingly complicated, further increasing the number of adjustable design parameters for an HDD servo system. This has resulted in the time-consuming process of manual parameter adjustment becoming an issue.

With this in mind, Toshiba Corporation has developed high-dimensional design parameter optimization technology, a Bayesian optimization approach that limits the search space by dividing high-dimensional design parameters into several groups of low-dimensional design parameters and alternately explores each design parameter group. This technology not only helps to reduce parameter adjustment time but also provides higher head positioning accuracy than manual parameter adjustment.

We applied the new technology to the adjustment of more than 100 design parameters for an HDD servo system and compared its performance with that of an HDD servo system with manually adjusted parameters using simulation. As a result, it reduces parameter adjustment time by two thirds while reducing the head positioning error by 13%.

We will also apply this technology to adjustment of design parameters for power semiconductor devices, control parameters for equipment, etc.

1.29 ISO/IEC 21823-4 Standard for IoT Data Interoperability



Example of ISO/IEC 21823-4 standard implementation to convert carbon footprint of products (CFP) data in various formats into Asset Administration Shell (AAS) data model

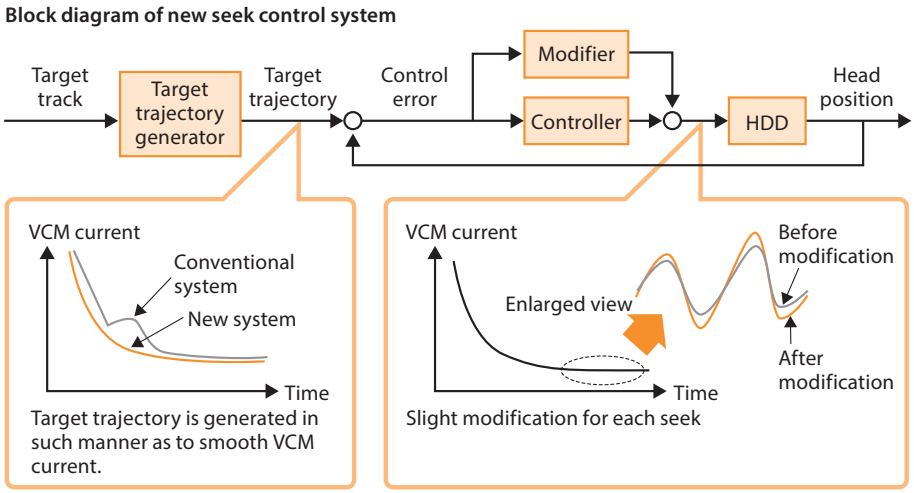
With the proliferation of Industry 4.0 and Society 5.0, it has become essential to ensure interoperability in data exchange between different devices and systems using different data modeling methodologies (i.e., information models), necessitating data interoperability support between different information models.

With this in mind, Toshiba Corporation is developing data interoperability technology using a model-driven approach to enable data conversion and exchange between different information models. To apply this technology to various IoT and Industrial IoT (IIoT) devices and systems, we proposed a new IoT interoperability specification which was adopted and published as the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 21823-4 "Internet of Things (IoT) — Interoperability for IoT systems" international standard in March 2022. We collaborated with the Information Processing Society of Japan (IPSJ) on the development of this standard in a project supported by METI of Japan.

At present, we are working on the implementation of the ISO/IEC 21823-4 standard to convert existing carbon footprint of products (CFP) data in different formats into a standard Asset Administration Shell (AAS) data model automatically so that the CFP data for all products can be visualized and managed, thereby achieving a CFP data ecosystem.

We tested the interoperability of CFP data in this ecosystem with systems from other vendors. The results indicated that ISO/IEC 21823-4 provides solid support for CFP data interoperability.

1.30 Long-Span Seek Control Technology to Improve Performance of Near-Line HDDs



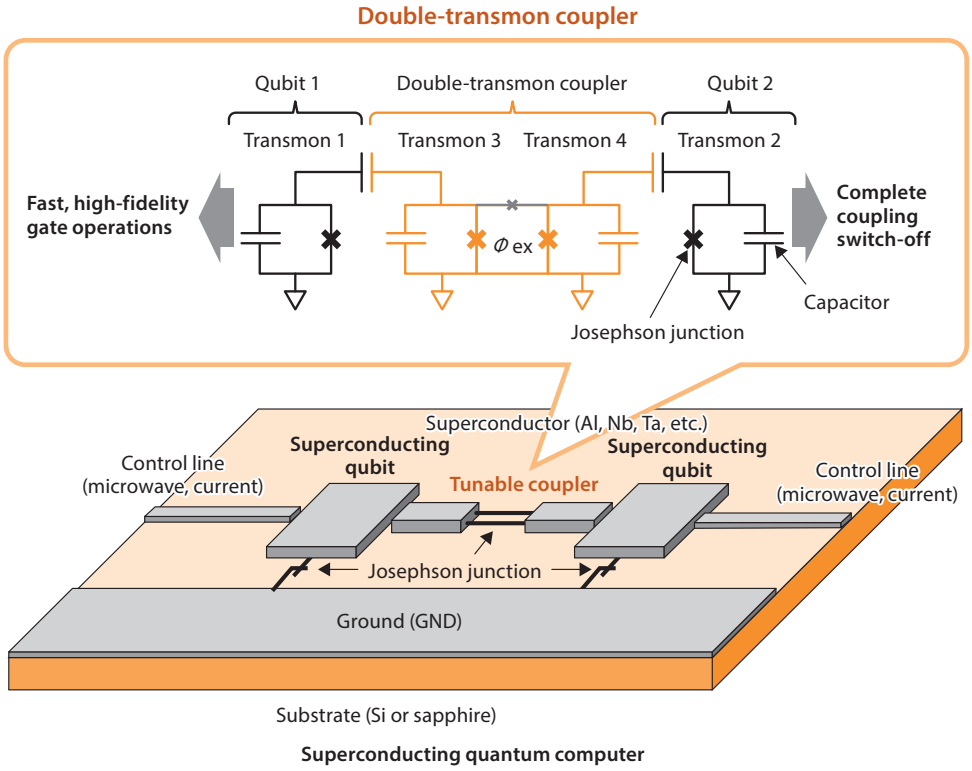
Block diagram of new seek control system to shorten seek time of near-line HDDs

Near-line HDDs for data centers are required for high-performance data access and high storage capacity. To improve data access performance, it is necessary to shorten the seek time so that the read-write head can move rapidly to the target data track. To shorten the seek time in long-span seek mode(*), it is especially important to shape the waveform of the voice coil motor (VCM) current immediately before the head reaches the target data track.

Conventionally, the VCM current waveform is shaped by switching the control gain during seek. This method produces discontinuities in the VCM current waveform, causing residual vibration of the head. To overcome this problem, Toshiba Corporation has developed a new long-span seek control system, which suppresses residual vibration by generating a target trajectory that provides smooth VCM current, making the head position follow this trajectory. Furthermore, the new technology reduces errors between the target trajectory and the head position by iteratively modifying the VCM current for each seek. As a result, we have achieved a 2.1% reduction in average seek time. The new seek control system will be used in our next-generation near-line HDDs.

(*) Seek control in which the seek distance is about 10 to 100% of the maximum seek distance.

1.31 Double-Transmon Coupler Capable of Improving Superconducting Quantum Computer Performance



Double-transmon coupler capable of improving superconducting quantum computer performance

A "tunable coupler" capable of controlling the coupling strength between qubits is a key component for improving the performance of superconducting quantum computers, which have shown remarkable advancements in recent times. The tunable coupler can meet conflicting requirements: strong coupling between qubits to achieve fast gate operations and complete switch-off of the coupling to mitigate quantum errors. Although a large difference between qubit frequencies is desirable to mitigate quantum errors between qubits, no tunable coupler has been able to meet these conflicting requirements under such conditions.

To resolve this issue, Toshiba Corporation has invented a double-transmon coupler, the world's first tunable coupler that satisfies both these requirements even for qubits with a large frequency difference(*). The newly developed double-transmon coupler enables not only complete switch-off of qubit coupling but also a fast gate operation of 24 ns and a high fidelity of 99.99%. It is expected that this novel component will help to further improve quantum computer performance.

(*) As of September 2022 (according to Toshiba Corporation research)

1.32 Compact and Accurate Neural Machine Translation Technology

System	Translation accuracy (BLEU score)*1		Translation quality Estimated accuracy*2 (Pearson's correlation)
	Japanese-to-Chinese and Chinese-to-Japanese	Japanese-to-English and English-to-Japanese	
Toshiba	Excellent 68.3/75.0	Good 22.7/38.1	Excellent (0.506)
A	Good 56.7/65.5	Good 25.2/39.1	Acceptable*3
B	Good 38.4/55.6	Good 26.2/35.8	–
C	Good 59.2/68.9	Acceptable 17.1/30.3	–
D	–	–	Good (0.428)

BLEU: bilingual evaluation understudy

∗1: Average of evaluations using multiple data sets

∗2: China Conference on Machine Translation (CCMT) 2021, sentence-level Chinese-to-English translation QE task

∗3: Based on comparison with D in another competition

Benchmarks of techniques for neural machine translation and translation quality estimation

Toshiba (China) Co., Ltd. has achieved neural machine translation (NMT), or machine translation using neural networks, at low cost on general servers. The new NMT system combines our state-of-the-art proprietary technologies to improve translation accuracy, using a simplified engine to eliminate the need for an expensive graphics processing unit (GPU).

Specifically, our NMT system employs a simple recurrent neural network (RNN) attention mechanism(∗1) in the transformer decoder (∗2), and a vocabulary table significantly reduced in size to achieve the world's highest-class accuracy for Japanese-Chinese and Japanese-English translation(∗3) while reducing the run-time to 1/8th.

In addition, we are collaborating with Beijing Jiaotong University on translation quality estimation (QE) technology R&D to enhance the added value of translation services. Our NMT system incorporating pre-fine-tuning and other steps won second place in the sentence-level English-German QE task at WMT22(∗4).

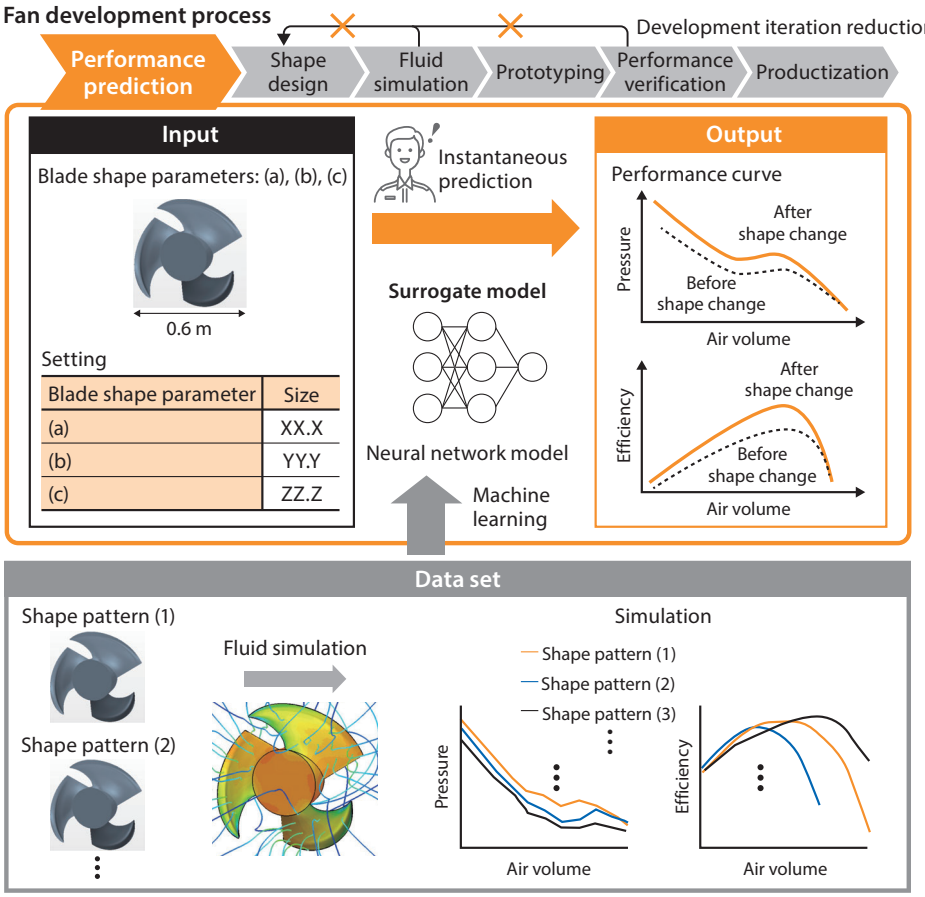
(∗1) A mechanism that dynamically identifies where to focus attention in input data

(∗2) Deep-learning model mainly used in the field of natural language processing

(∗3) As of September 2021 (according to Toshiba (China) Co., Ltd. research)

(∗4) EMNLP 2022 (The 2022 Conference on Empirical Methods in Natural Language Processing) workshop (WMT: The Seventh Conference on Machine Translation)

1.33 Fan Performance Prediction Technique Using Surrogate Model



Fan performance prediction technique using surrogate model

Fan development teams often conduct repeated design and performance verifications, relying on experience and intuition until all performance requirements are satisfied, prolonging development times.

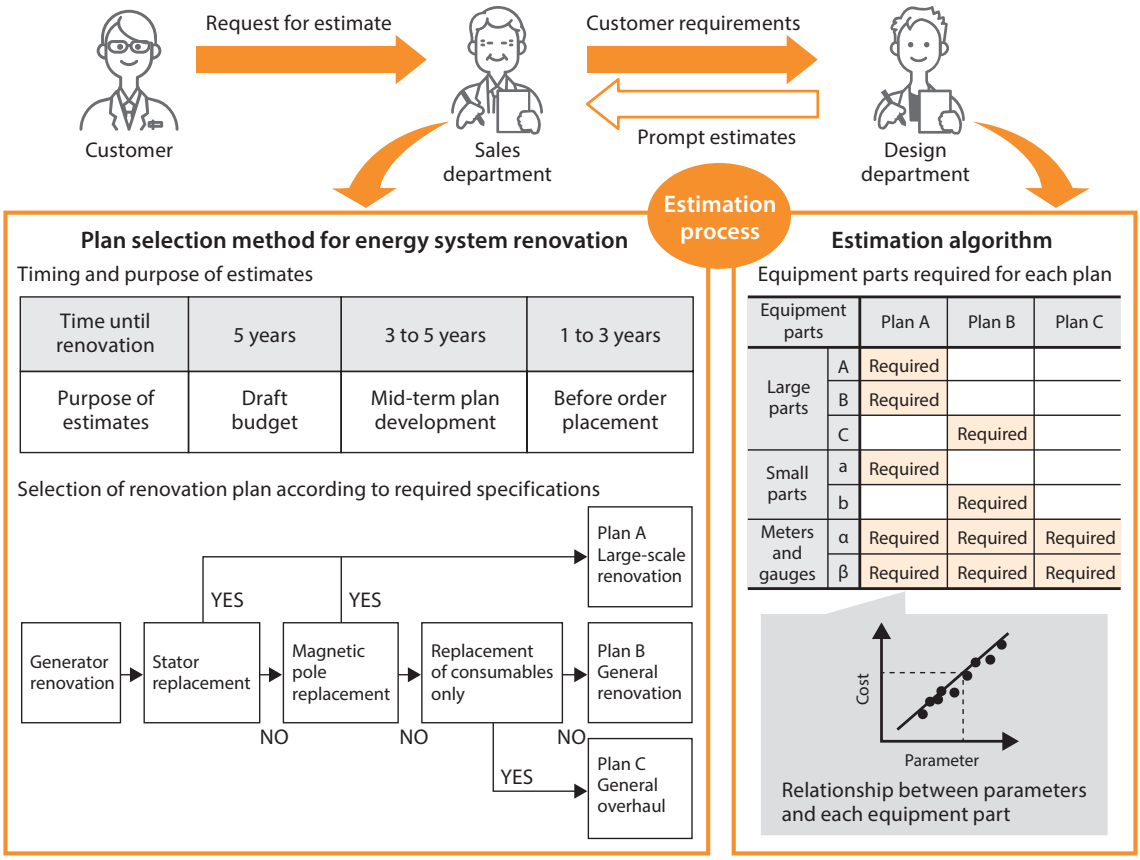
To eliminate dependence on individual expertise and reduce development times, Toshiba Corporation has developed a fan performance prediction technique using a surrogate model(*). This technique can predict the impact of the blade shape on fan performance instantaneously.

We employed fluid simulation to prepare 30 data sets on changes in performance (e.g., air volume, static pressure, and efficiency) caused by changes to blade shape parameters. Based on these data sets, we created a surrogate model with a relative prediction error of less than 1% using a neural network model suitable for modeling nonlinear phenomena. Because the surrogate model can predict the performance of an unknown blade shape in less than one second, it is possible to search for blade shapes that satisfy the required specifications in less than one ten-thousandth of the fluid simulation run-time.

In the future, we will apply this technique to various products at the Toshiba Group to improve design and development efficiency.

(*) An alternative model built by machine learning based on the results of multiple simulations

1.34 Fast Estimation Process Based on Classified Renovation Services and Parametric Prediction



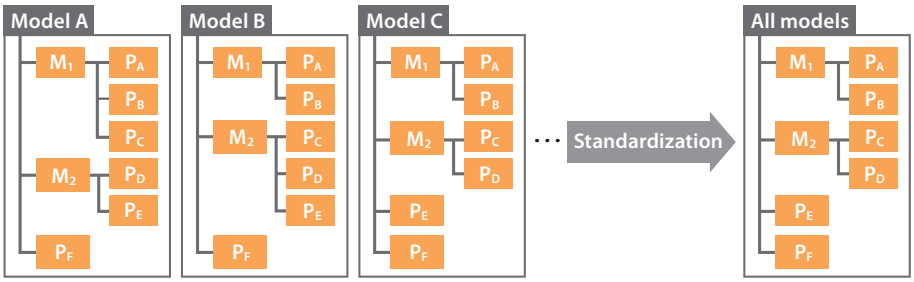
Estimation processes to rapidly provide customers with draft budget required for energy system renovation

For energy system renovation projects, it is sometimes necessary to provide service outlines and cost estimates at an early stage when system specifications are not yet well defined. However, cost estimation is time-consuming because facility environments are different, making it necessary to consider the design of each part.

To resolve this issue, Toshiba Corporation has developed fast estimation processes that use pre-formulated plans according to the required renovation services. First, we investigated the existing plant facility environments and the parts installed at each and classified the required services that vary from plant to plant into several plans based on their relationships with the required specifications. Next, we organized cost-dominant parts and associated them with parameters related to the plant size to create an estimation algorithm. We also devised a method that allows the sales department to select a plan based on customer requirements.

The new estimation processes have made it possible to create an estimate promptly with sufficient accuracy, even for estimations requiring cross-departmental involvement. We have applied these estimation processes to renewable power plants in Japan and confirmed that they shorten estimation time by about 90%.

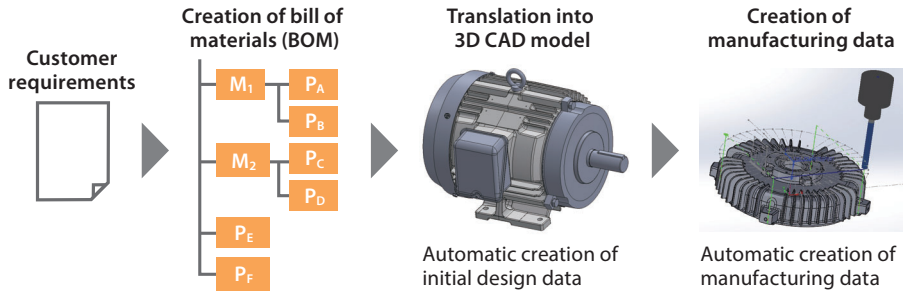
1.35 Standardized Product Module Configurations and Seamless Data Linkage to Improve Design and Manufacturing Productivity



Each product model has different module configurations.

M_1, M_2: modules P_A to P_F: parts

Unified module configuration common to industrial motors



Linkages of data from customer requirements to design and manufacturing phases

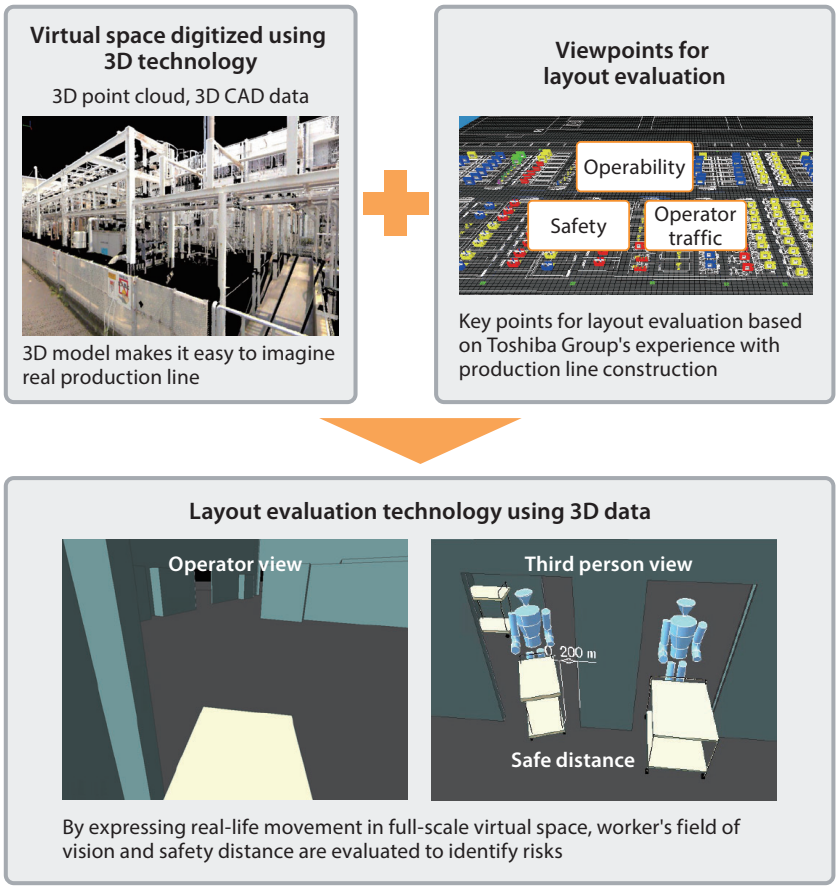
Modular design is an efficient method for creating various products by combining pre-defined modules. Conventionally, it has been difficult to modularize industrial motors efficiently because there were too many variations of modules with different parts configurations and design rules.

To resolve these issues, Toshiba Corporation has standardized the module configurations and design rules for each product model, thereby reducing the number of module variations by 90% while maintaining the capability to meet customer requirements.

In addition, we have developed a design environment that can convert customer requirements into data and accordingly select the necessary parts from a database. This makes it possible to create a bill of material (BOM) automatically and convert the customer requirements into a 3D computer-aided design (CAD) model for efficient design verification. Therefore, the new design environment simplifies the verification of product models. Moreover, we have created a 3D computer-aided manufacturing (CAM) environment that utilizes 3D CAD models for machining processes with manufacturing constraints.

Because engineering data flow seamlessly from the customer requirement phase all the way to the design and manufacturing phases, we have succeeded in reducing the design processes and iterations, achieving a 40% reduction in design time.

1.36 Technology to Evaluate Layout of Production Lines Using 3D Data

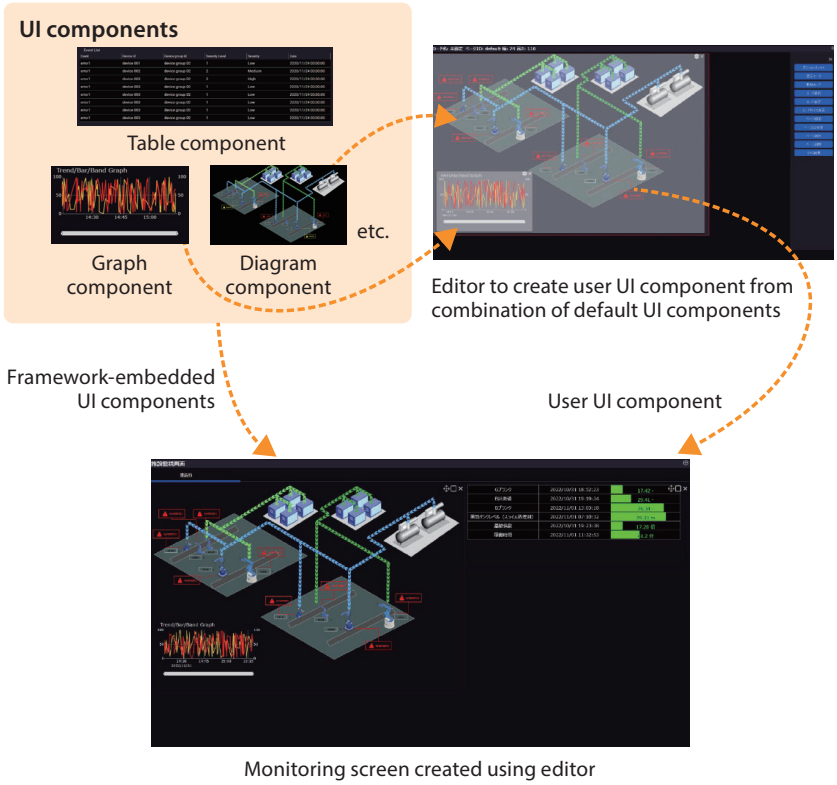


Outline of layout evaluation technology for production line using 3D data

In order to perfect the layout of a new production line in a short period of time, Toshiba Corporation has developed a layout evaluation technology that provides a close-to-reality feel in a 3D virtual space. The new technology converts a point cloud measured with a 3D laser scanner into a 3D model to visualize production lines in a building and construct an evaluation environment in virtual space. This 3D model allows us to examine the layout of a production line from the viewpoints of both operators and third parties, for example, using virtual reality (VR), and evaluate its operability and safety based on our experience. The 3D model makes it possible for all concerned parties to share a common perception.

We applied this technology to the construction of a production line for electronic substrates and examined the operator traffic in a factory. As a result, we were able to identify the risk of bumping against someone coming out of a blind spot. In addition, by simulating the detailed movement of a hand lifter and measuring its distance from obstacles, we identified the risk of the hand lifter contacting an obstacle due to insufficient safe distance. By identifying such risks at an early stage, we were able to implement remedial measures prior to the construction of the production line, contributing to the commencement of mass production on schedule.

1.37 Low-Code UI Framework to Facilitate Provision of Highly Customizable Monitoring Screens for O&M



Example of monitoring screen designed with combination of UI components

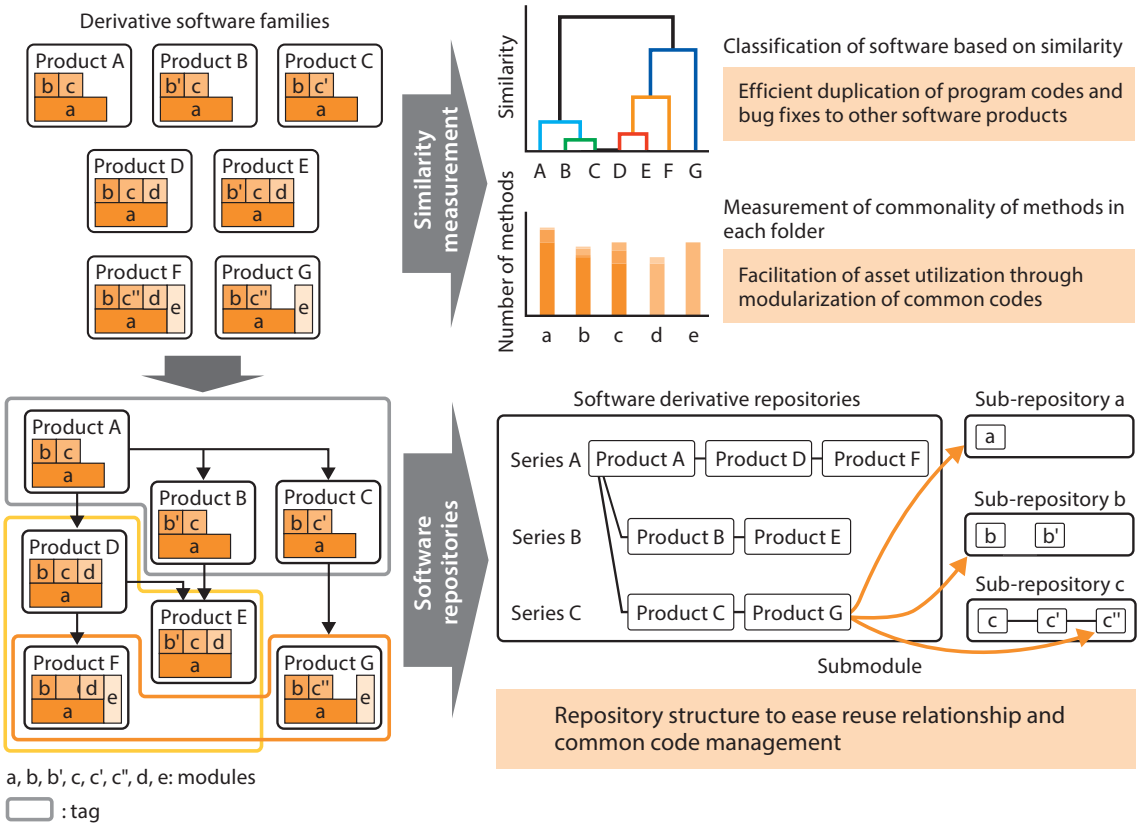
In the field of O&M at factories and infrastructure facilities with monitoring systems, the monitoring screen user interface (UI) needs to be updated promptly according to monitoring tasks and equipment replaced during operations. However, significant time is sometimes required to customize monitoring screens because of the need to place an order with monitoring system vendors even if only a few changes are necessary.

To resolve this issue, the Toshiba Group has developed a low-code UI framework composed of UI components such as tables and graphs as well as an editor that allows monitoring system users to create screens on their own using the UI components. Furthermore, this UI framework also allows users to create their own UI components by combining default UI components.

Users are now able to visualize the facility status and customize their monitoring screens themselves to meet their task needs.

Our next step is to add features that provide recommendations on the optimal placement of UI components and subsequent operations based on user operation records, thereby improving the monitoring screen user experience (UX).

1.38 Software Modularization to Facilitate Asset Utilization



Overview of modularization of existing software assets based on similarity analyses

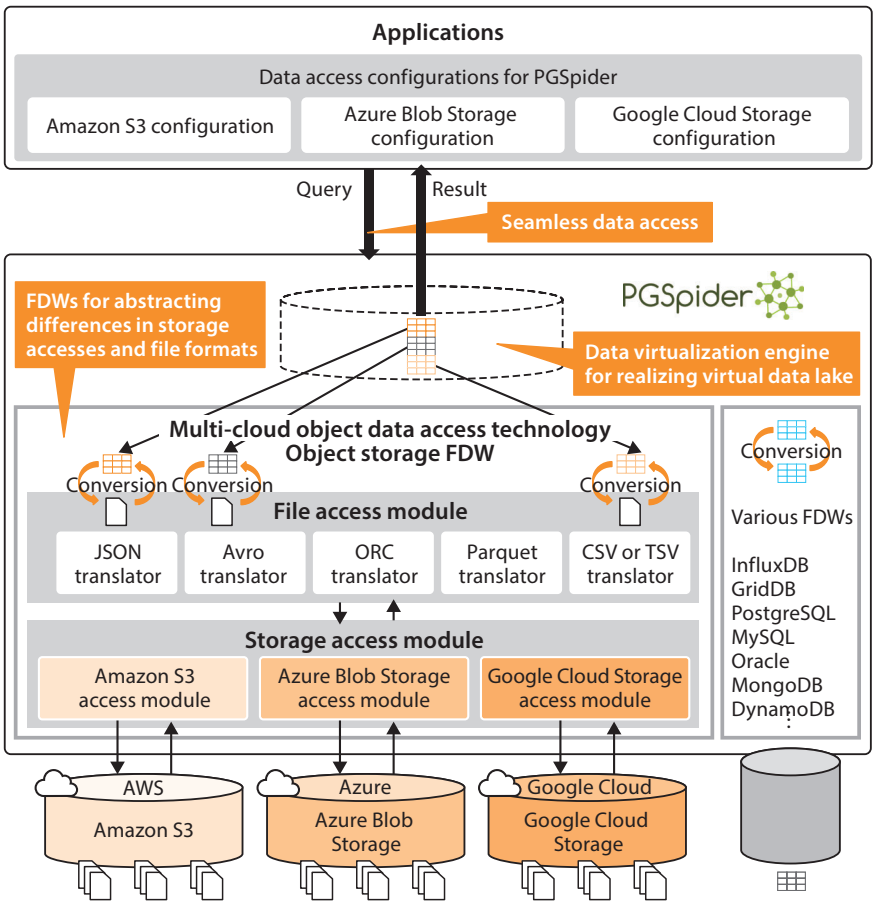
As software becomes increasingly larger-scaled and more complicated despite progressively shorter development times, software assets must be used more effectively. However, as more types of software derived from existing software increases, managing the differences and similarities among derivatives is growing more complicated.

To resolve this issue, Toshiba Corporation has developed a technique to analyze and visualize reuse relationships and commonalities among software derivatives based on a measure of similarity. This technique makes it possible to separate variable and fixed portions of software for modularization, thereby simplifying management of differences and commonalities. In addition, development efficiency can be improved by reusing source codes in variable pieces and duplicating changes to the common pieces across all derivatives.

Furthermore, management of the derivative software families can be simplified by (1) aggregating the derivative software families into one repository, (2) representing derivative relationships with branches, and (3) separating the common pieces in a partial repository.

By using this new technique, we will promote management of diverse derivative software families according to customer requirements and leverage our software assets to improve development efficiency.

1.39 Multi-Cloud Object Data Access Technology



FDW: foreign data wrapper
S3: Simple Storage Service
JSON: JavaScript Object Notation
CSV: comma-separated values
TSV: tab-separated values
AWS: Amazon Web Services
ORC: Optimized Row Columnar

Overview of multi-cloud object data access technology

In order to deliver data services and business, vendor independence is necessary to allow flexible selection of cloud service vendors at optimal cost and provide technology that allows seamless object data access across vendors.

To meet these requirements, Toshiba Corporation has developed multi-cloud object data access technology for online object storage services that enables seamless access to various files managed online. This technology incorporates a PostgreSQL(*) extension module to enable data access using a common Structured Query Language (SQL) interface. It abstracts differences in the interface among cloud services and converts data between internal data models and various file formats. Furthermore, when combined with our PGSpider data virtualization engine, this technology makes it possible to access data across different cloud object storage services.

(*) A relational database management system available as open-source software