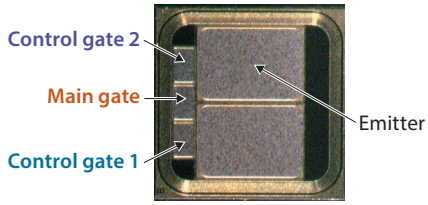
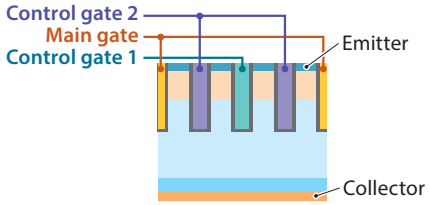
1. Research and Development

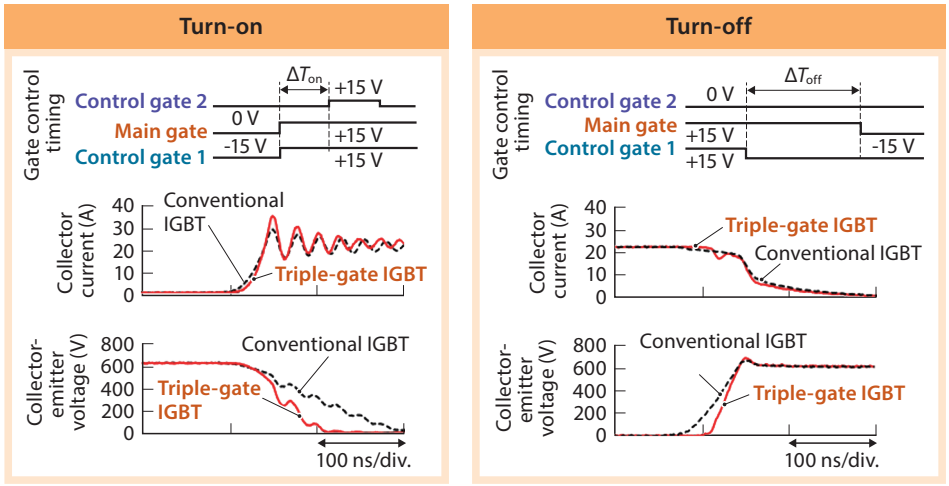
1.1 Triple-Gate IGBT Contributing to Realization of Highly Efficient Power Electronics Systems



Prototype triple-gate IGBT

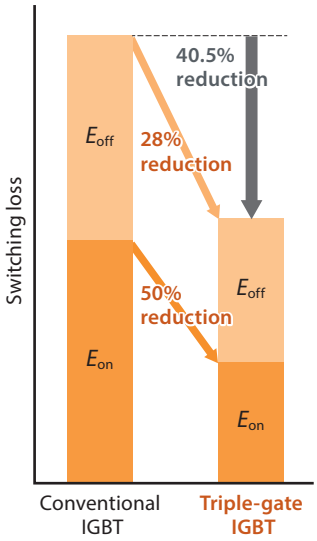


Cross-sectional image of triple-gate IGBT



T: time div.: division

Comparison of switching waveforms of conventional and triple-gate IGBTs



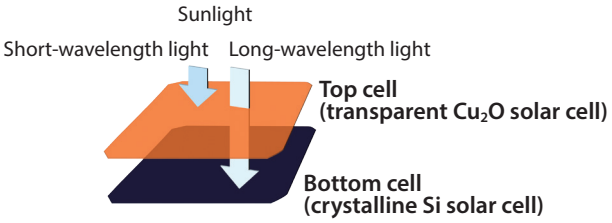
Comparison of switching losses of conventional and triple-gate IGBTs

Toshiba Corporation has developed a triple-gate insulated-gate bipolar transistor (IGBT) and a new gate control technique to achieve a substantial reduction in switching loss.

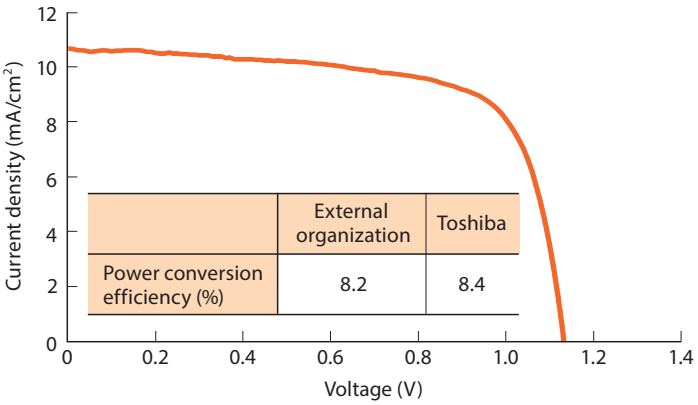
The IGBT is a power semiconductor used for electric vehicle and industrial inverter applications. Although semiconductor manufacturers have invented various device structures to improve the electrical characteristics of the IGBT, this approach is reaching its limits.

The newly developed IGBT has three gate terminals; namely, the main gate, control gate 1, and control gate 2. The new gate control technique optimally controls the on-off states of these gates to achieve high-speed carrier injection during turn-on and high-speed carrier discharge during turn-off. When combined with this gate control technique, the new triple-gate IGBT provides a 50% lower turn-on loss (E_{on}) and a 28% lower turn-off loss (E_{off}) than the conventional IGBT, resulting in an up to 40.5% reduction in total switching loss. The new IGBT and gate control technique will greatly contribute to the realization of highly efficient power electronics systems.

1.2 Low-Cost, High-Efficiency Tandem Solar Cells Using World's Most Efficient Cu_2O Cell



Schematic diagram showing structure of tandem solar cell with transparent cuprous oxide (Cu_2O) cell



Current density-voltage characteristics and benchmark comparison of efficiency of Cu_2O cells

Active area of solar cell is 40 × 40 mm. We intend to gradually increase the size of this area.

Large Cu_2O cell under development

Toshiba Corporation has developed a new low-cost, high-efficiency tandem solar cell with a small footprint that can generate a large amount of electricity. The newly developed tandem solar cell consists of a transparent solar cell using a p-type cuprous oxide (Cu_2O) layer and a crystalline silicon (Si) solar cell. The transparent Cu_2O cell, the key to a tandem solar cell, is composed of copper and oxygen. Since both copper and oxygen are naturally abundant elements, the Cu_2O solar cell helps to realize low-cost tandem solar cells.

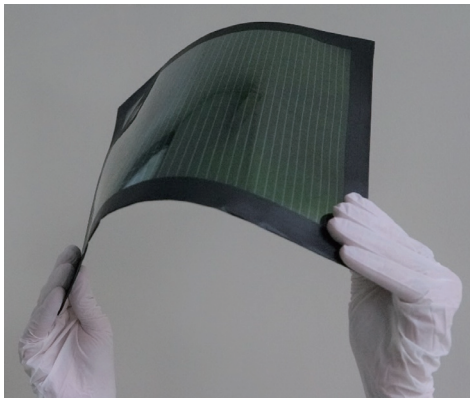
The new Cu_2O cell provides the world's highest power conversion efficiency (PCE) of 8.4%(*1) because of the reduced impurities in its absorbing layer. When it is combined with a Si cell with a PCE of 25%, the resulting tandem solar cell is estimated to have a PCE of 27.4%, exceeding the world's highest efficiency of 26.7% for Si cells(*2).

We are planning to develop larger Cu_2O solar cells with a size equivalent to that of mass-produced Si solar cells. In addition, we will establish manufacturing technology for larger Cu_2O solar cells by FY2025 while further improving their PCE to make them a practical solution for electric vehicles and other forms of electric mobility, thereby contributing to the realization of a carbon-neutral society in the future.

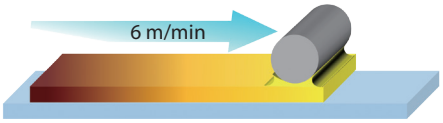
(*1) *Appl. Phys. Lett.* 119, 242102 (2021); https://doi.org/10.1063/5.0072310

(*2) As of December 2021 (as researched by Toshiba Corporation)

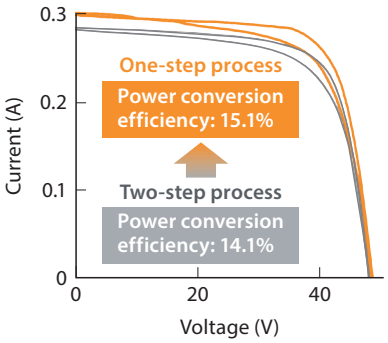
1.3 Film-Based Perovskite Photovoltaic Module with Power Conversion Efficiency Equivalent to That of Polycrystalline Si Solar Cells



Film-based perovskite photovoltaic module



Schematic of meniscus coating method using one-step process



Current-voltage characteristics of film-based perovskite module with area of 703 cm^2

Film-based perovskite solar cells are lightweight, thin, and bendable. These features make them installable on various buildings and places such as lightweight factory roofs and building walls where conventional Si solar cells have not been installable before. Therefore, film-based perovskite solar cells are expected to help expand the use of renewable energy toward the realization of carbon neutrality.

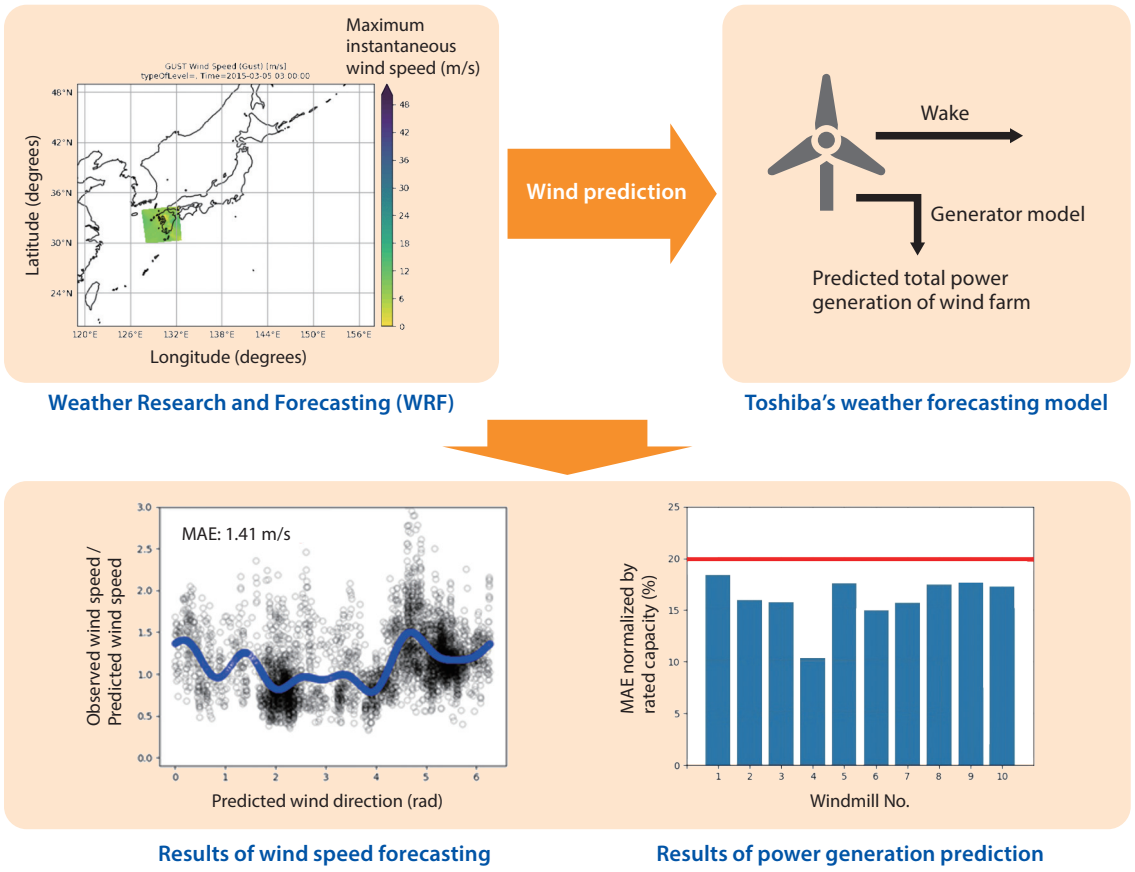
Toshiba Corporation is developing a meniscus coating method capable of depositing a perovskite layer in one step instead of the two steps required up to now. The newly developed meniscus coating method has achieved a coating speed of 6 m/min(*1), which is expected to be fast enough to realize the mass production of perovskite solar cells.

In addition, a film-based module with an area of 703 cm^2 fabricated with the one-step process has achieved a power conversion efficiency of 15.1% in comparison with the 14.1% attained by a module fabricated with the two-step process. This is because the one-step process provides uniform film quality and other benefits. The enhanced power conversion efficiency of the newly developed perovskite photovoltaic module is comparable to that of mass-produced polycrystalline Si solar cells and is the world's highest efficiency for large film-based perovskite photovoltaic modules(*2).

(*1) As measured by Toshiba Corporation for coating a perovskite layer with a size of 5 × 5 cm

(*2) As of September 10, 2021, for 100 cm^2 or larger film-based perovskite solar modules with a plastic substrate (as researched by Toshiba Corporation)

1.4 Wind Power Generation Forecasting Based on Numerical Weather Prediction



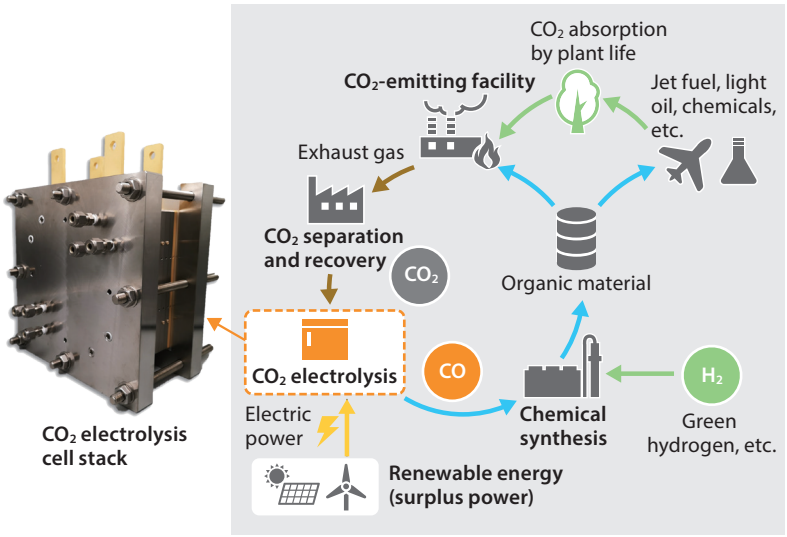
Outline of power generation prediction system for wind farms using WRF model

To achieve carbon neutrality by 2050, the amount of electricity generated by wind power systems is expected to further increase in Japan. In order to ensure stable electricity supply and demand in deregulated electricity markets, highly accurate wind power generation forecasting is crucial along with the introduction of a feed-in premium (FIP) system.

Toshiba Corporation has conducted a detailed investigation of information related to vertical wind speed distribution (mean wind speed, turbulence intensity, atmospheric stability, etc.) using the Weather Research and Forecasting (WRF) model, and developed a wind speed prediction model that can accommodate large wind turbines by taking into account the effects of both the geographical topography and the wind turbine itself. This model includes wind shear, turbulence, and wakes for wind speed prediction. We have also developed a technique to accurately predict the amount of electricity generated by a wind farm by entering the predicted wind speed into a wind turbine generator model. We confirmed that day-ahead prediction using this technique at multiple sites can achieve a mean absolute error (MAE) of less than 20% (in normalized percent of the rated capacity).

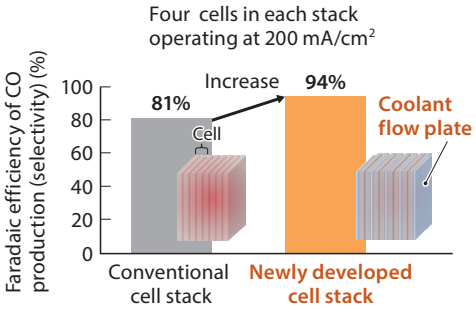
In the future, we will apply this technology to our renewable energy aggregation business.

1.5 Power-to-Chemicals: Technology for CO_2 Recycling via Electrolysis



H_2: hydrogen

CO_2 electrolysis cell stack and concept of power-to-chemicals (P2C)



Comparison of faradaic efficiency of CO production by conventional and newly developed CO_2 electrolysis cell stacks

Since it is essential to reduce dependence on fossil fuels in order to achieve carbon neutrality, various industries are actively developing technologies to recycle carbon dioxide (CO_2) as a resource.

For CO_2 recycling, Toshiba Corporation has power-to-chemicals (P2C) technology to electrochemically reduce CO_2 to carbon monoxide (CO), which can be used to produce various fuels and chemicals. Leveraging our P2C technology, we have now developed a CO_2 electrolysis cell stack (width: 23 cm, depth: 13 cm, height: 23 cm). Consisting of several electrolysis cells, the newly developed cell stack has achieved a CO_2 processing rate of 60 NL/h(*1), which is equivalent to up to 1.0 ton of CO_2 per year, the world's highest level for CO_2 electrolysis cell stacks with the same footprint operating at room temperature(*2).

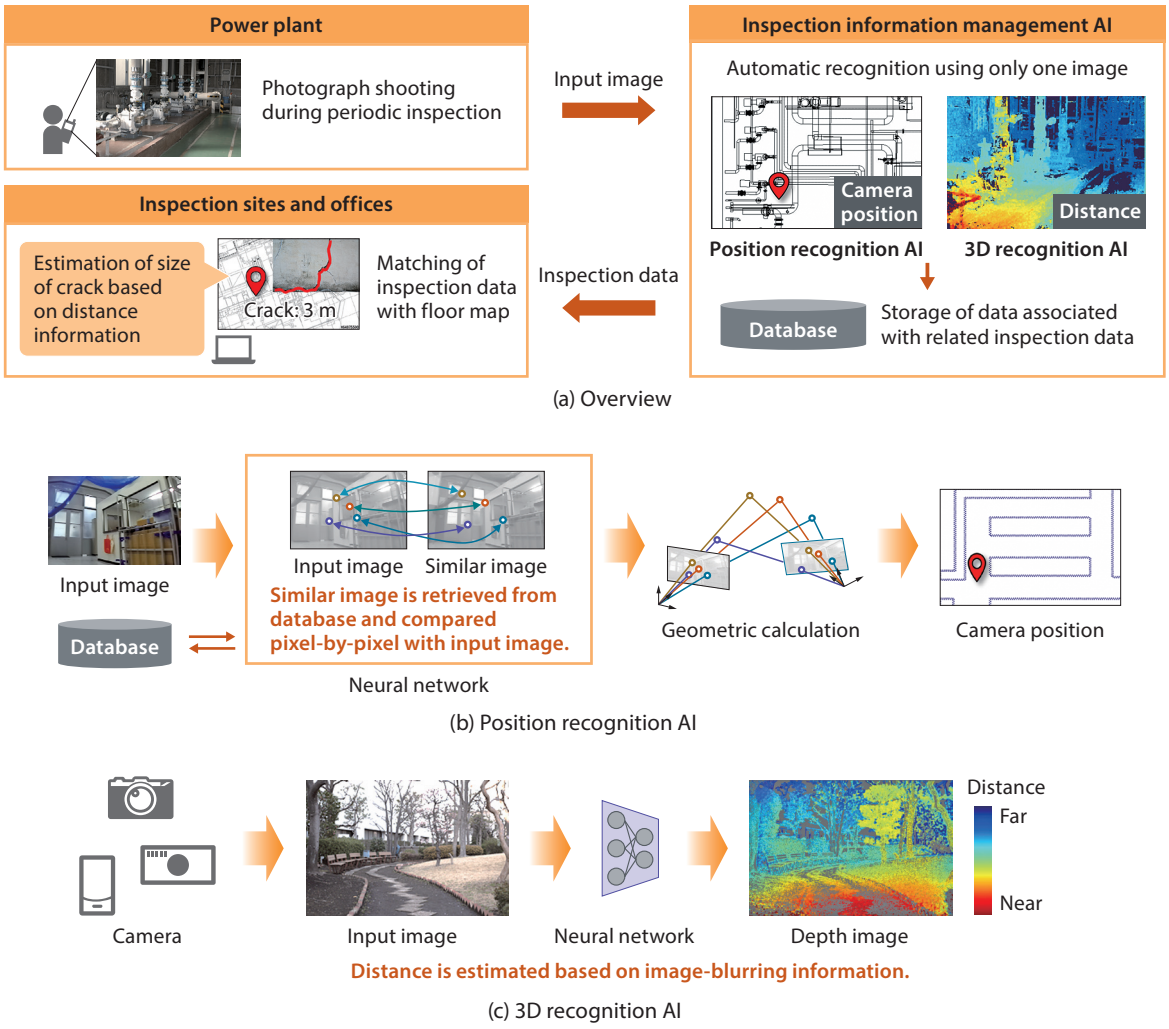
Heat can be a serious problem for cell stacks because it causes the processing rate to degrade. To prevent this problem, we have developed a unique stack structure with a cooling mechanism. Because the amount of CO_2 processed per unit footprint area can be increased by stacking multiple cells, this structure helps to reduce the product footprint while increasing the amount of CO_2 processed. This is a significant step toward the practical application of P2C.

This work is partially supported by the Ministry of the Environment of Japan.

(*1) Volume per hour at standard temperature (0°C) and pressure (1 atm).

(*2) As of March 2021 (as researched by Toshiba Corporation)

1.6 Inspection Information Management AI



Overview of inspection information management AI

To improve the efficiency of inspection rounds and maintenance tasks at infrastructure facilities, information related to inspections is often managed using photographs and global positioning system (GPS) location data. When the GPS does not work in indoor environments such as inside a power plant, inspectors generally take photographs of cracks and other signs of deterioration, record their locations and sizes manually, and organize the photographs, associating them with floor plans.

In order to alleviate the burden of this information management, Toshiba Corporation has developed an artificial intelligence (AI) technique capable of recognizing the shooting location and the degree of equipment deterioration, including the size of cracks, simply by analyzing a single photograph. This technique, called the inspection information management AI, consists of two AI algorithms: (1) a position recognition AI for determining camera positions from photographic images and (2) a three-dimensional (3D) recognition AI that recognizes the subject size.

First, the position recognition AI creates a database in advance that associates photographic images with camera positions in a floor map so that images similar to an input image to be inspected can be retrieved from the database. The camera position of the input image is calculated geometrically based on the pixel-by-pixel correspondence between the input and retrieved images.

The 3D recognition AI relies on the fact that blurs in a photograph depend on the camera-to-subject distance. This AI algorithm is trained in advance based on differences in blurring depending on the camera-to-subject distance. It also recognizes the subject size from the camera-to-subject distance.

In this way, the inspection information management AI can recognize both the camera position and the subject size simply by means of photographs uploaded to a server, thereby improving the efficiency of inspection rounds and maintenance tasks even for indoor facilities such as power plants where the GPS does not work.

1.7 Small and High-Resolution Light-Receiving Device with Improved Sensitivity for Solid-State Lidar with 200-Meter Range

Accompanying the spread of electronic commerce, the amount of cargo being transported in Japan has been increasing, while on the other hand the country is seeing an increase in natural disasters and road failures due to extreme weather events such as heavy snow and rain, posing a serious safety hazard for transportation. Transport automation and infrastructure monitoring using light detection and ranging (lidar) are effective measures for enhancing the efficiency and safety of transportation. Lidar sensors, i.e., infrared laser distance sensors based on the time-of-flight principle, are attracting much attention because of their conspicuous advantages over cameras. However, in order to commercialize lidar sensors, it is essential to reduce their cost and size.

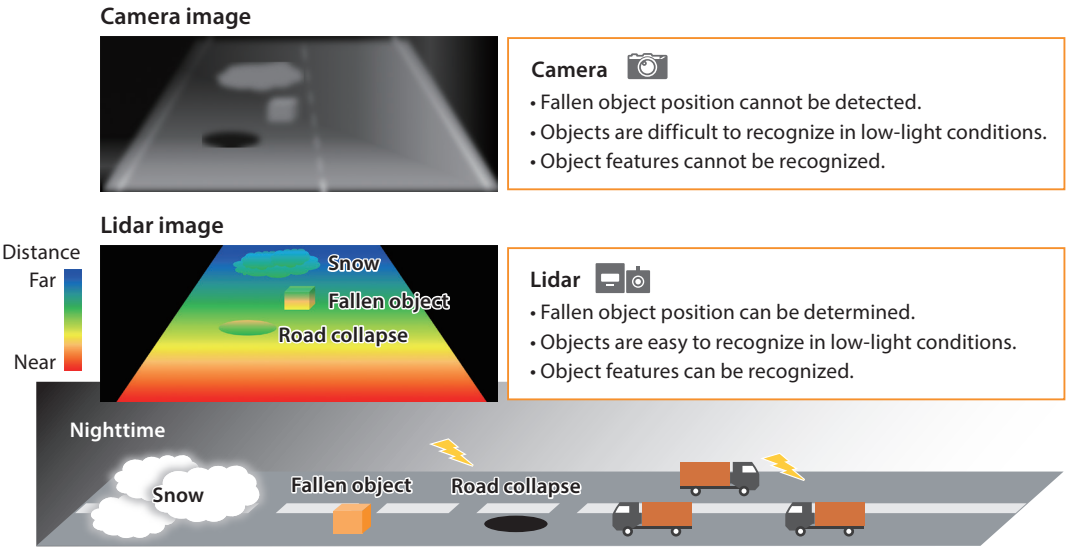
Toshiba Corporation has responded to this situation by developing a solid-state lidar sensor using a light-receiving device. While our first prototype had a volume of 1 500 cm^3 and a detection range of up to 200 m, the second prototype has a much smaller volume of 350 cm^3 yet it achieves higher image resolution and an equivalent detection range through the use of an enhanced light-receiving device and high-density component mounting techniques.

The newly developed device consists of an array of light-receiving cells controlled by transistors. To reduce the size of the transistor module, the new light-sensing device is fabricated using insulating trenches between the transistors and light-receiving cells. This eliminates the need for a buffer layer to protect the transistors.

These innovations made it possible to reduce the size of the light-receiving device by 75% and increase its light sensitivity by 50% in comparison with the first prototype. In addition, we leveraged our expertise in high-density component mounting to reduce the overall size of the lidar sensor to 350 cm^3 while achieving fourfold image resolution.

Furthermore, the latest prototype incorporates a performance compensation technology for the light-receiving device and provides superior durability for outdoor use under all weather conditions.

We will continue our R&D efforts to further increase the detection range, improve the image resolution, and reduce the size of the lidar sensor while exploring new lidar applications for robots, drones, and small security devices.



Advantages of monitoring system for transportation infrastructure using light detection and ranging (lidar)

Second prototype

Distance: 200 m (same)
Image resolution: 1 200 × 84 pixels (4 times)
View angle: 24 × 12° (6 times)
Volume: 350 cm^3 (1/4)

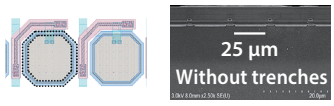
* Values in parentheses show comparisons with first-generation prototype.

Top-class distance range and image resolution

World's smallest size

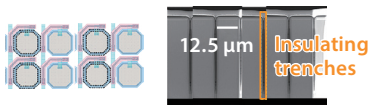
Technologies for fabricating highly sensitive, compact devices

First-generation prototype



50% increase in light sensitivity with 75% smaller volume

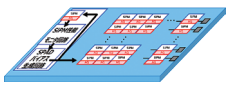
Second-generation prototype



Automatic temperature compensation and high-density component mounting technologies

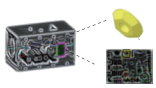
Temperature change

On-chip monitoring and compensation of performance of light-receiving device



Wind resistance, vibration

High-density component mounting for size and weight reduction



Performance of second-generation prototype lidar unit and technologies applied

1.8 Robots and Systems Capable of Flexibly Handling Complex Logistics Tasks to Improve Productivity

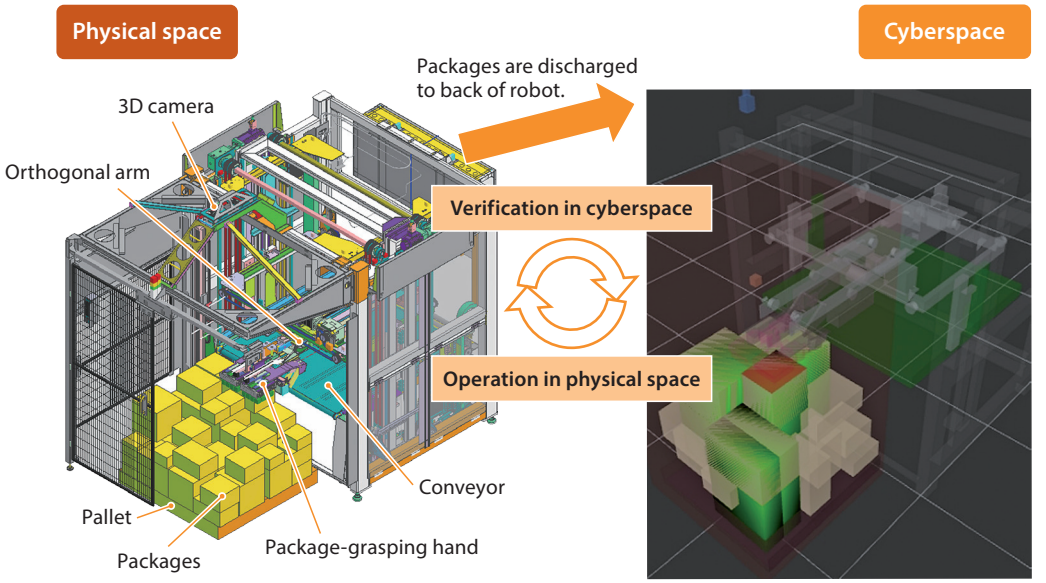
A wide variety of products are handled in e-commerce, and operators are relied on to perform complex logistics tasks. However, the recent spread of e-commerce has led to labor shortages in the logistics industry, spurring demand for new automation technologies capable of handling the ever-increasing number of complex tasks in a flexible manner.

To meet this demand, Toshiba Corporation is improving the intelligence of logistics robots using AI. We have now developed a planning technology that allows logistics robots to unload various packages from stacks according to their layout conditions.

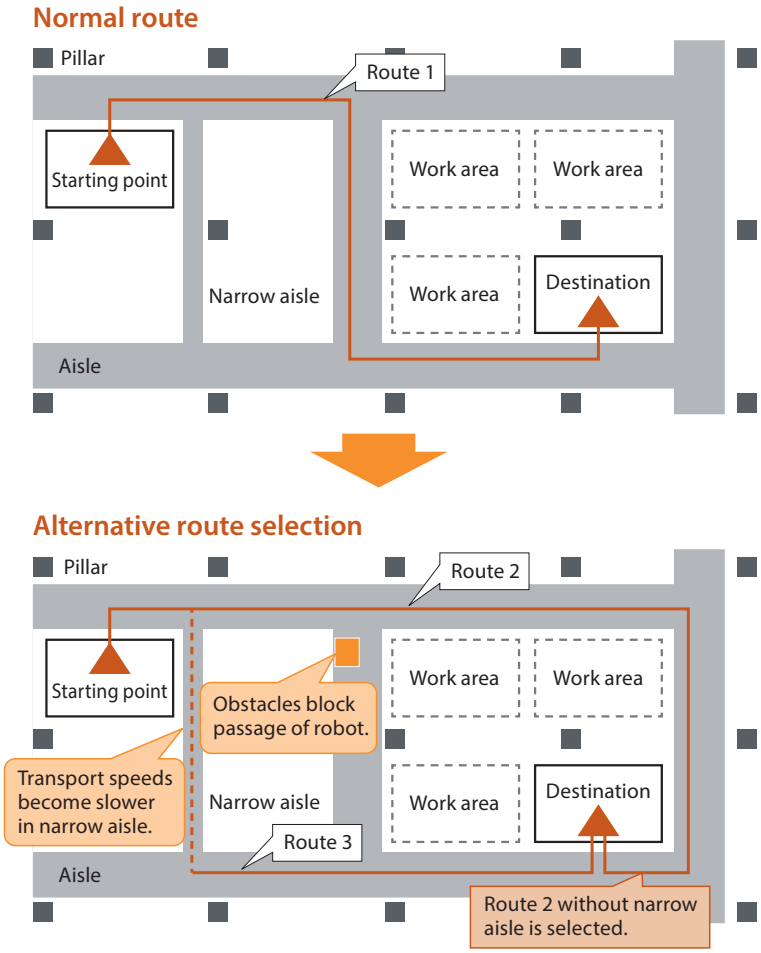
Logistics centers handle diverse types of packages, including those of the same size stacked in neat rows and those of different sizes stacked randomly. Although depalletizing robots have been available to unload heavy packages from pallets or carts, it has been difficult to handle stacks containing an assortment of different packages. The newly developed planning technology uses digital twins in cyberspace to determine whether robots can grasp and discharge packages in overlapping operations flexibly and safely. We have confirmed that a prototype robot incorporating this technology can handle various stacked packages while achieving a roughly 30% improvement in unloading performance.

In addition, we have developed a solution for finding the shortest route taking into consideration the conditions of the logistics center such as the width, layout, and traffic restrictions of aisles. This solution consists of an instruction system and a suite of transportation robots that move around the aisles autonomously while checking the surrounding conditions. When it is difficult for a robot to make route decisions on its own due to a situation such as temporary traffic restrictions, the instruction system selects an alternative route that is estimated to be the fastest one.

We will use the new solution to improve logistics productivity.

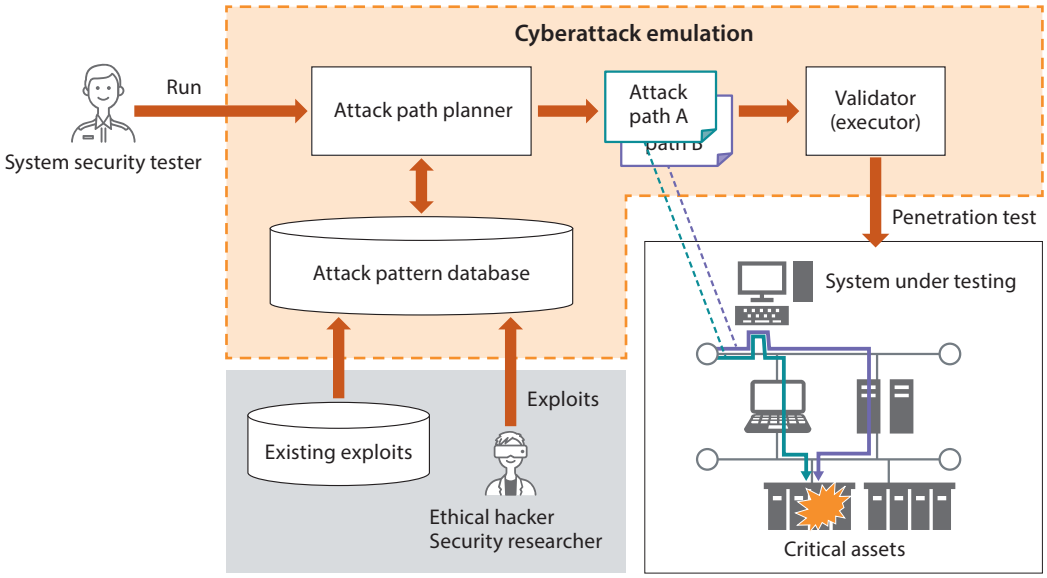


Depalletizing robot adopting digital-twin approach for flexibly planning complex movements to unload various stacked packages



Selection of rapid transportation route from multiple routes

1.9 Cyberattack Emulation Technology to Evaluate Security Risks of Industrial Control Systems



Outline of cyberattack emulation technology to evaluate security risks using attack path planner and validator

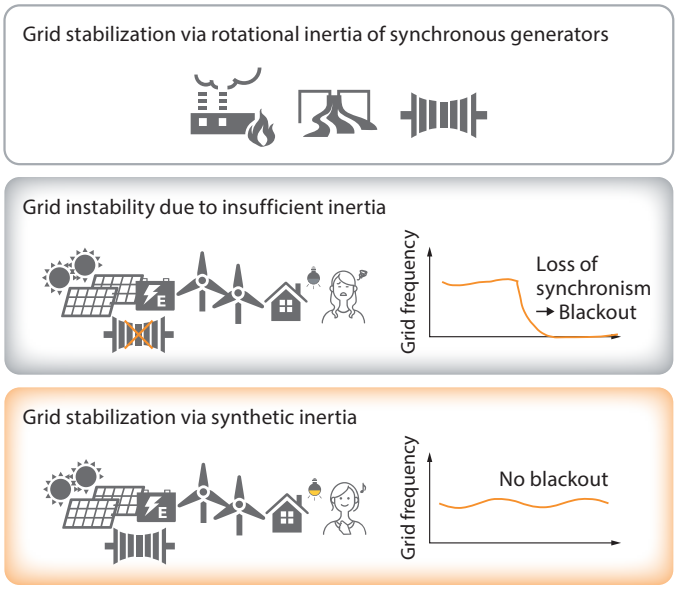
The number of serious incidents in critical infrastructure caused by cyberattacks has been increasing. Two types of technologies are essential to maintain the security of infrastructure systems: technologies to evaluate the impact of cyberattacks on infrastructure systems and technologies to protect them from cyberattacks.

Toshiba Corporation has now developed a technology to evaluate the impact of cyberattacks by emulating possible attacks in a virtual environment. This technology consists of two steps. The first step determines possible attack paths using the attack path planner, which examines vulnerabilities identified or predicted in each component of the system being evaluated. In the second step, the validator emulates attacks according to the given paths.

In order to create executable attack paths in real-world systems, the attack path planner uses an attack pattern database that associates each vulnerability with an exploit.

We have developed this technology in cooperation with Peraton Labs. Its implementation is available as an open source. We will continue to improve it through practical experiments in collaboration with other companies to protect critical infrastructure from various types of cyberattacks.

1.10 Evaluation of Inertia of Grid-Forming Inverters with Virtual Synchronous Generator Control



Concept of stabilization of electricity generation using inertia-supporting control technology in microgrid system

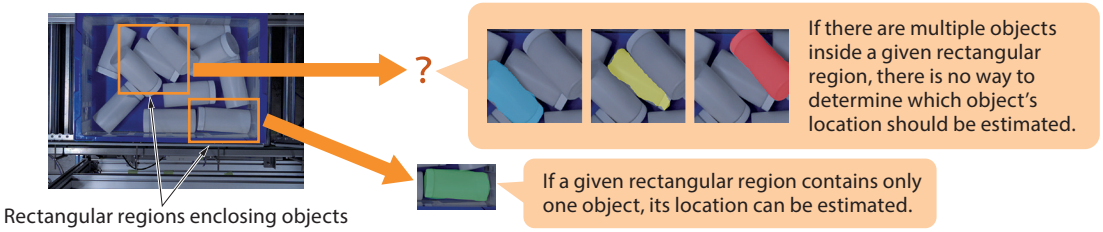
Demonstration facility to verify grid-forming inverter with inertia-supporting control technology

The stability of a power grid is maintained by the large rotational inertia of synchronous generators at thermal, hydroelectric, and other power stations. However, there is concern that the level of inertia of power systems might become insufficient in the future because of the ever-increasing use of renewable energy sources. In addition, off-grid microgrid systems are becoming an increasingly promising solution to sustain electricity self-sufficiency even in the event of a major blackout due to a disaster. This is more so in the case of remote areas and islands where black-start capability is required to restore power systems from a blackout.

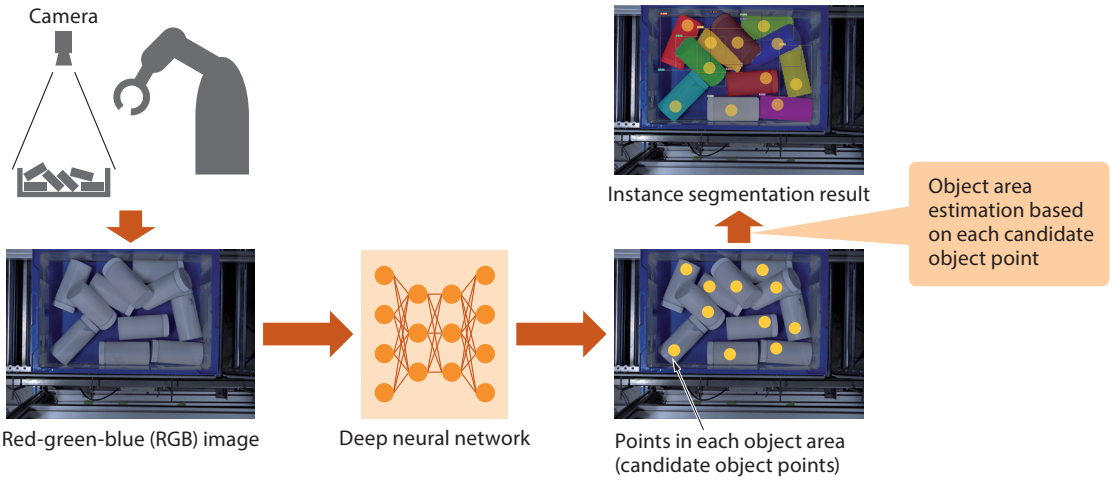
Under these circumstances, Toshiba Corporation has developed a battery energy storage system (BESS) with both synthetic inertia and black-start capabilities. The newly developed BESS incorporates grid-forming (GFM) inverters with inertia-supporting control based on a virtual synchronous generator (VSG). We built a microgrid consisting of five inertia-supporting GFM inverters and one diesel synchronous generator (SG) and conducted a demonstration test to evaluate the enhancement of grid stability due to synthetic inertia. As a result, we confirmed that the inertia-supporting GFM inverters help to enhance the stability of renewable-dominated microgrids.

This research is supported by the Ministry of the Environment of Japan under the Low Carbon Technology Research, Development and Demonstration Program.

1.11 Technology for Accurate Instance Segmentation of Overlapping Objects



Problem faced by conventional instance segmentation technology

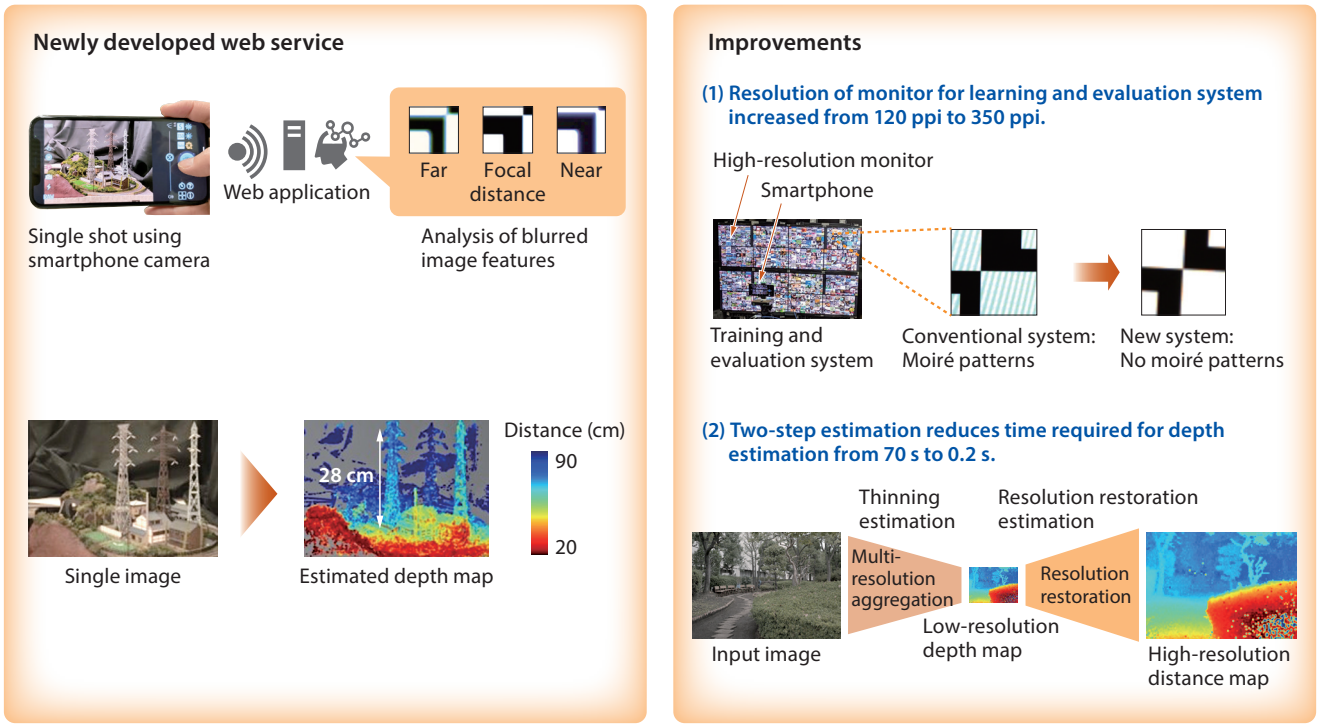


Outline of instance segmentation technology using candidate points on individual objects

In the field of logistics, the automation of loading and unloading processes using robots is progressing. Instance segmentation technology is utilized to locate individual objects in images captured by an overhead camera. For accurate instance segmentation, it is necessary to distinguish overlapping objects. The conventional instance segmentation method first detects rectangular regions that enclose individual objects and then estimates the area of each object inside its rectangular region. The conventional method cannot, however, estimate object areas accurately when there is a significant amount of overlap due to the existence of multiple objects in a rectangular region.

To solve this problem, Toshiba Corporation has developed a new instance segmentation technology that first detects points on an object (candidate object points) and then estimates the object's location based on the candidate object points. We evaluated the object detection performance of this technology using the WISDOM dataset, one of the publicly available robotic picking datasets. As a result, it was confirmed that the newly developed instance segmentation method improves the detection rate from 76.4% using the conventional method to 82.8% under conditions with almost the same computational cost. Our instance segmentation technology makes it possible to locate overlapping objects accurately.

1.12 Depth Measurement from Image Taken by Smartphone Camera



ppi: pixels per inch

Overview of web service for depth measurements from a single photograph taken by a smartphone camera and improvements over conventional method

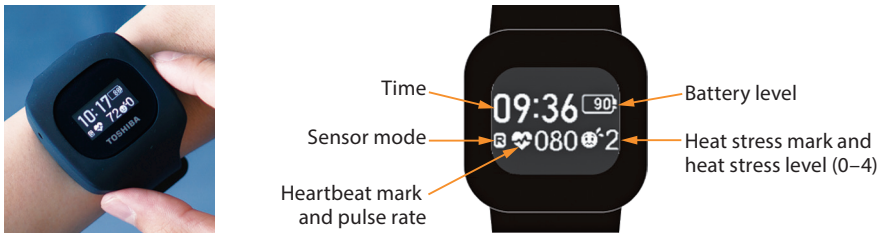
For efficient inspection and maintenance of infrastructure, a quick and easy method is required to measure the size of areas of deterioration. To measure the size of an object in an image, it was previously necessary to use a multi-camera or lidar system capable of measuring depths.

To simplify infrastructure inspection and maintenance, Toshiba Corporation has developed a web application that makes it possible to measure the depth of objects in an image from a single photograph taken by a smartphone. In order to realize the new web application, we improved 3D aberration mapping, a method of measuring the depth of a subject based on the shapes and coloration of blurs caused by lens aberrations. Moreover, to support the use of small cameras, we developed a high-resolution learning and evaluation system that does not cause moiré patterns.

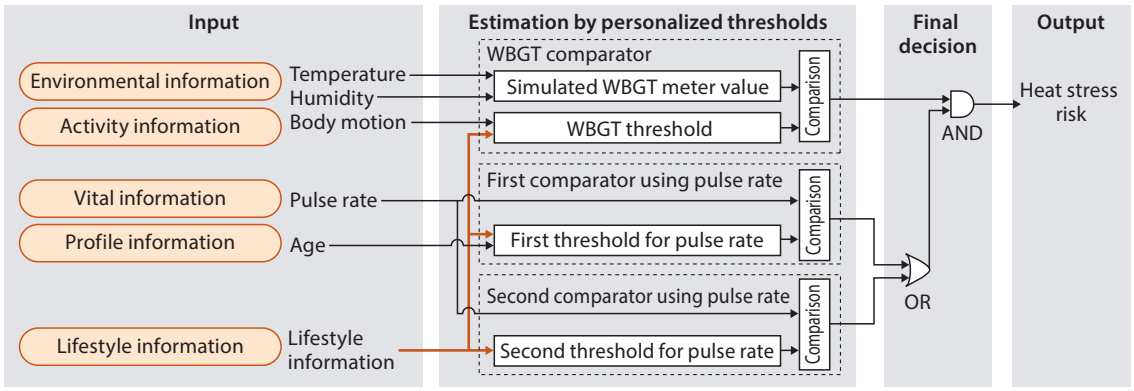
To reduce the response time of the web service, we also developed a two-step depth estimation algorithm consisting of estimation at reduced resolution followed by the reconstruction of a distance map at high resolution. This algorithm has reduced the time required for depth estimation from 70 seconds to less than 0.2 seconds.

Our next step is to improve robustness against camera noise to support dark images.

1.13 Heat Stress Risk Estimation for Workers Utilizing Wearable Sensor



MULiSiTEN™ MS100 wristband type sensor



Flowchart of estimation of worker's heat stress risk

Wet-bulb globe temperature (WBGT) is used as an international standard to estimate the risk of heat stress on workers' physical health in an intense heat environment. However, WGBT is based only on the effects of temperature and humidity and does not take into account individuals' differences in heat tolerance. Workers are therefore frequently interrupted by heat alarms when they are working in a sultry environment even when they are not in poor physical condition.

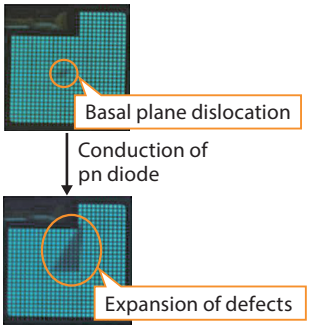
To solve this problem, Toshiba Corporation has developed a method for estimating heat stress risk based on an individual's vital signs, profile, and lifestyle in addition to the conventional environmental information. Vital signs are monitored using a wearable device.

The new method automatically adjusts the thresholds for heat stress estimation according to a worker's lifestyle (medical history, body mass index [BMI], exercise habits) and vital signs (pulse rate) to realize personalized estimation and determines the heat stress level by combining the results of multiple threshold comparisons.

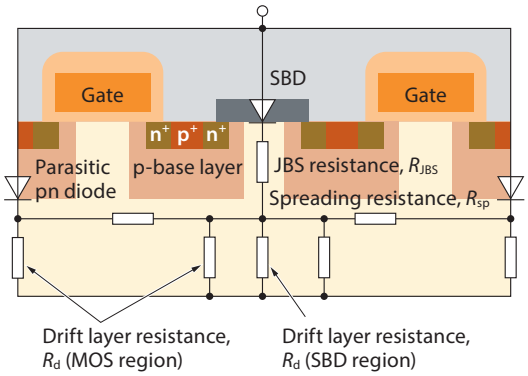
Using actual worksite data, we confirmed that at a false rejection rate (i.e., the rate at which actual heat stress cases were incorrectly rejected) of 0% , the false acceptance rate (i.e., the rate at which non-heat stress cases were incorrectly evaluated as heat stress cases) of the new method was reduced to 17.7%, 5.7 points lower than that obtained using the conventional method.

Following further improvement, we incorporated this method into the MULiSiTEN™ MS100 wristband type sensor and released it in June 2021.

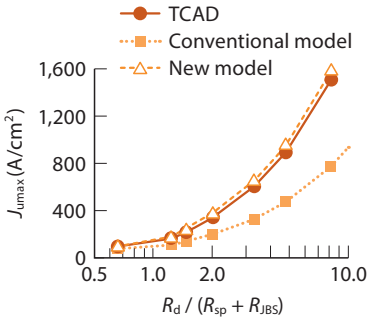
1.14 SBD-Embedded SiC MOSFETs with Parasitic pn Diode Having Improved Clamping Capability and Long-Term Reliability

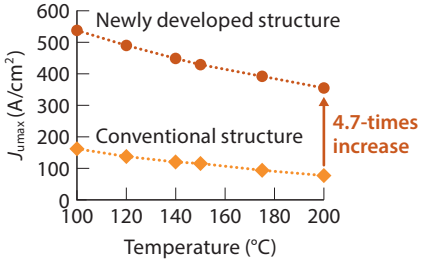


Expansion of defects caused by conduction of parasitic pn diode



New equivalent circuit model of SBD-embedded SiC MOSFET





P+: heavily doped p-type semiconductor
TCAD: technology computer-aided design

N+: heavily doped n-type semiconductor
JBS: junction barrier-controlled Schottky diode

Reproduction of current density at which parasitic pn diode conducts (J_{umax}) and J_{umax} of newly developed SBD-embedded SiC MOSFET

Improvement of J_{umax} using new equivalent circuit model of SBD-embedded SiC MOSFET

To realize a carbon-free society, it is important to improve the performance of power devices and thereby reduce the energy loss of power electronics devices. Silicon carbide (SiC) has excellent physical properties as a substrate for power devices, but the reliability of an SiC metal-oxide-semiconductor field-effect transistor (MOSFET) degrades when its parasitic pn diode conducts, causing defects to expand from the SiC substrate.

To prevent conduction of the parasitic pn diode, the Toshiba Group is developing SiC MOSFETs with an embedded Schottky barrier diode (SBD). We have created a new equivalent circuit model of the SBD-embedded SiC MOSFET that simply and accurately represents the maximum current density at which the parasitic pn diode does not conduct (J_{umax}). This model makes it possible to correctly identify the device parameters that determine J_{umax}.

By designing and fabricating devices based on this model, we have succeeded in increasing the J_{umax} of SBD-embedded SiC MOSFETs by 4.7 times, improving their reliability. This is a promising result for the future application of SBD-embedded SiC MOSFETs at temperatures exceeding 200°C.

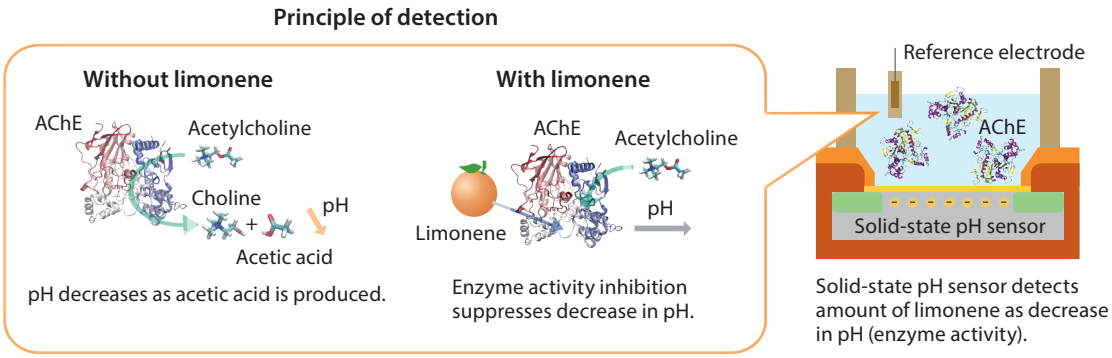
1.15 Highly Selective Odor Molecule Detection Technology Utilizing Enzymatic Reaction

Fruit quarantine inspections at airports and quarantine stations are crucial to prevent the invasion of exotic plants and parasites, which are generally screened visually by human inspectors or using scent detection dogs as part of the immigration procedure. However, an alternative method is becoming necessary to handle the increasing movement of people and goods across international borders.

Odor molecules are small, volatile, and have few structural characteristics. It is therefore difficult to selectively identify odor molecules with a commercially available gas sensor using an artificial sensitive membrane. On the other hand, sensors using olfactory receptor cells have been widely researched and are known to be excellent in terms of molecular recognition. It is difficult, however, to commercialize olfactory receptor sensors because of their instability.

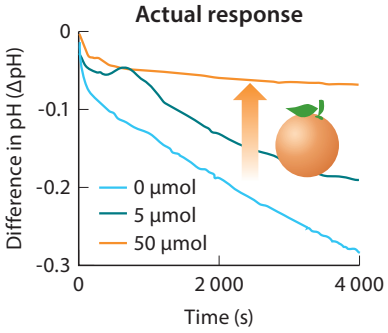
Under these circumstances, Toshiba Corporation has been focusing attention on enzymes, a group of proteins that are widely used commercially because of their molecular recognition specificity and stability. We have developed an odor detection technology that uses an enzyme whose reaction is inhibited by a specific odor molecule as well as a solid-state pH sensor. As a result, we have succeeded in the quantitative detection of limonene, a typical odor molecule that occurs naturally in citrus fruit. We have confirmed that the new method provides high sensing selectivity among limonene, molecules with a structure similar to limonene, and other odor molecules with the same molecular weight.

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



AChE: acetylcholinesterase (enzyme)

Mechanism of limonene detection using enzyme and solid-state pH sensor

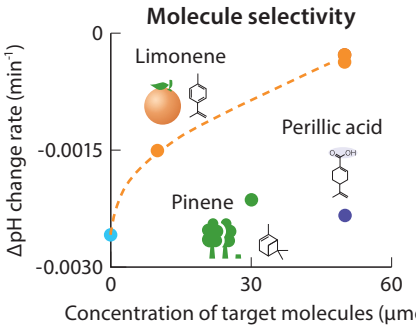


pH slope becomes shallower with increasing amount of limonene.

↓

Quantitative detection of limonene

Quantitative detection of limonene applying enzyme reaction inhibition



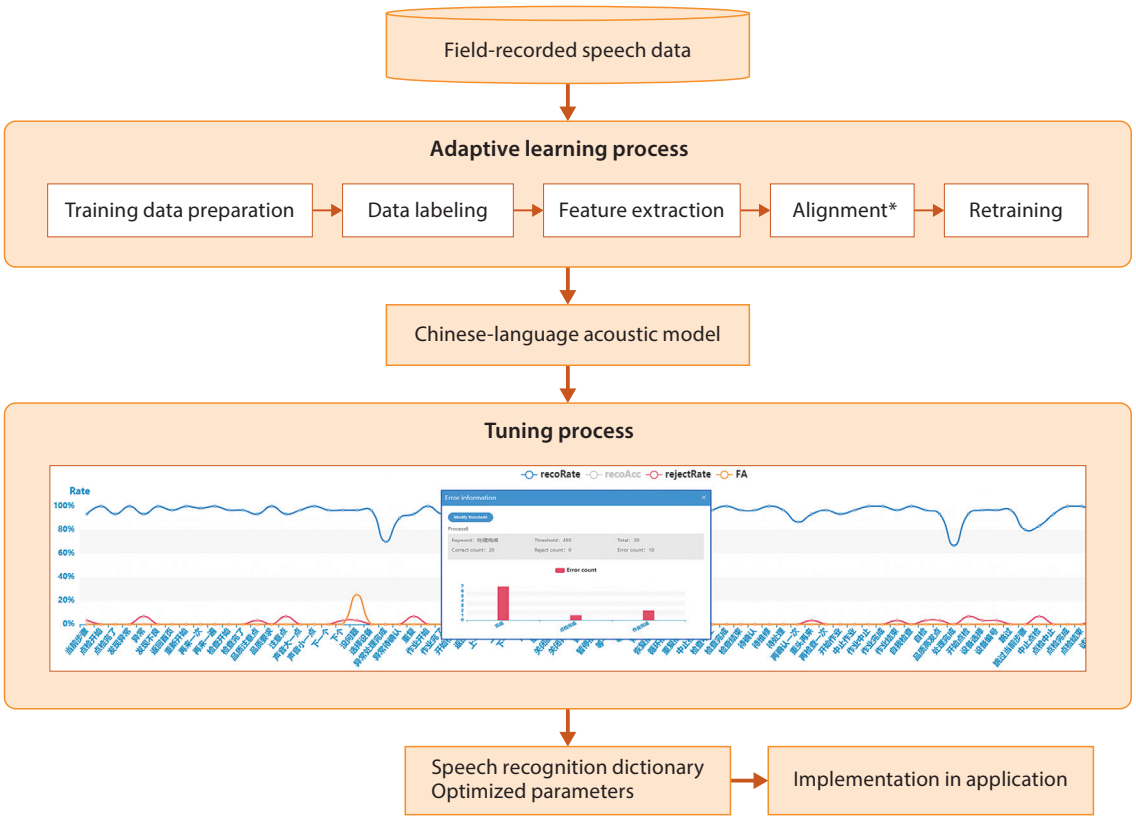
Decreasing rates of pH in response to pinene and perillic acid were almost the same as that of blank sample case.

↓

Highly selective detection of limonene

Selectivity of sensing of limonene compared with other molecules

1.16 Voice Trigger Optimization Technology to Realize Practical Speech Recognition Accuracy in Noisy Environments



* Estimation of position of each phoneme in speech data

Flow of processes in voice trigger optimization technology

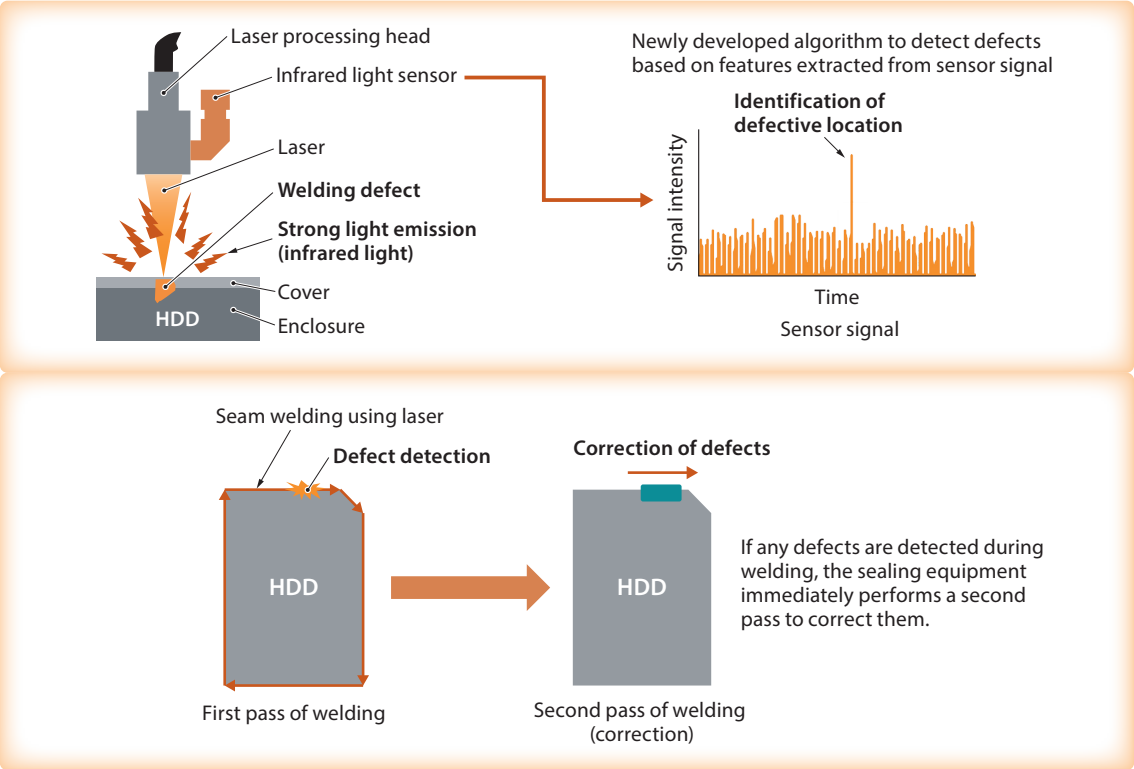
All industries have been investing a great deal of effort to improve work efficiency in factories. It is difficult, however, to achieve sufficient speech recognition accuracy for practical use in noisy environments.

To improve speech recognition accuracy in real fields such as on factory floors, Toshiba (China) Co., Ltd. has developed a voice trigger optimization technology. Specifically, we first recorded multiple speakers on the factory floor. Then, using the recorded speech data for adaptive learning and acoustic model training, we developed an environment in which dictionaries and parameters for speech recognition can be seamlessly optimized.

In an experiment conducted on the factory floor of Toshiba Carrier Air Conditioning (China) Co., Ltd., the newly developed speech recognition application achieved a remarkable accuracy of 95.3%, up from 52.4%.

At present, we are endeavoring to improve the work efficiency of inspection, checking, operation, and other processes using speech recognition.

1.17 HDD Sealing Equipment with Welding Monitoring and Correction Functions



Overview of welding monitoring and correction functions of HDD sealing equipment

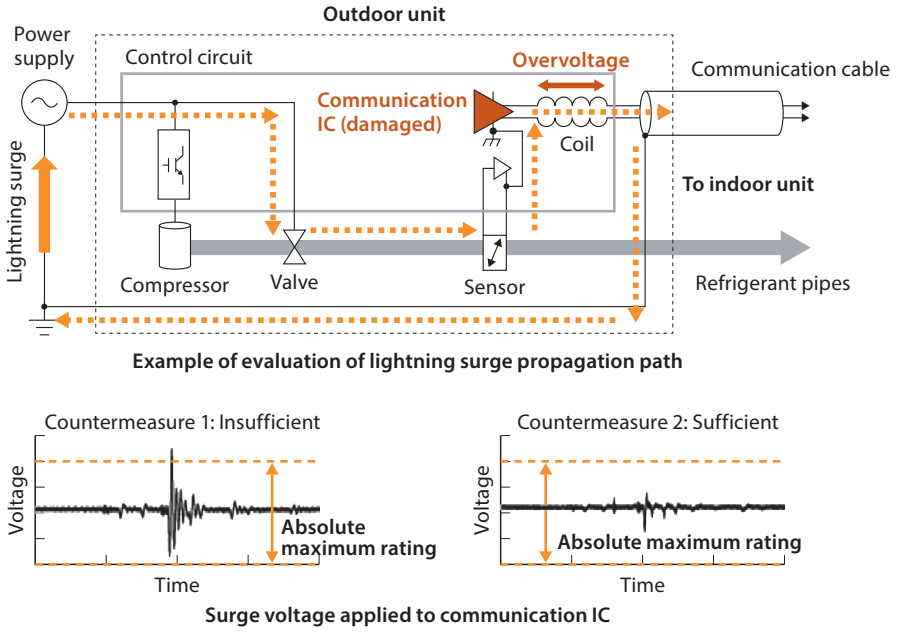
Large-capacity 3.5-inch helium-filled hard disk drives (HDDs) are mainly used in data center servers. Toshiba Corporation has developed sealing equipment for these HDDs that is equipped with welding monitoring and correction functions.

To seal helium in the HDD, a seam welding machine is used to laser-weld the entire circumference of the cover with the HDD enclosure in one pass. Conventionally, the first step after welding was an automatic inspection of the HDD's appearance and a helium leakage test. If an HDD had any defects, it was returned to the sealing equipment for correction.

In contrast, the newly developed sealing equipment is equipped with both welding monitoring and correction functions. The welding monitoring function uses an infrared light sensor to measure the laser intensity at the working point in real time and detects welding defects based on the features extracted from the sensor signal. In the event of any defects being detected, the correction function repairs them immediately in a second pass of welding. Consequently, the new sealing equipment requires less than one-tenth the correction time of the conventional equipment.

In the future, we will introduce this sealing equipment to new manufacturing lines to improve productivity.

1.18 Efficient Implementation of Countermeasures against Electrical Equipment Failures Caused by Lightning Surges



Example of visualization of lightning surge propagation path in air conditioner and evaluation of effectiveness of each measure

The lightning surge immunity of electrical equipment is tested during its development. Since the voltage to ground rises by more than a thousand volts during a lightning surge test(*), it has been difficult to measure the voltage applied to electrical equipment using conventional testing instruments.

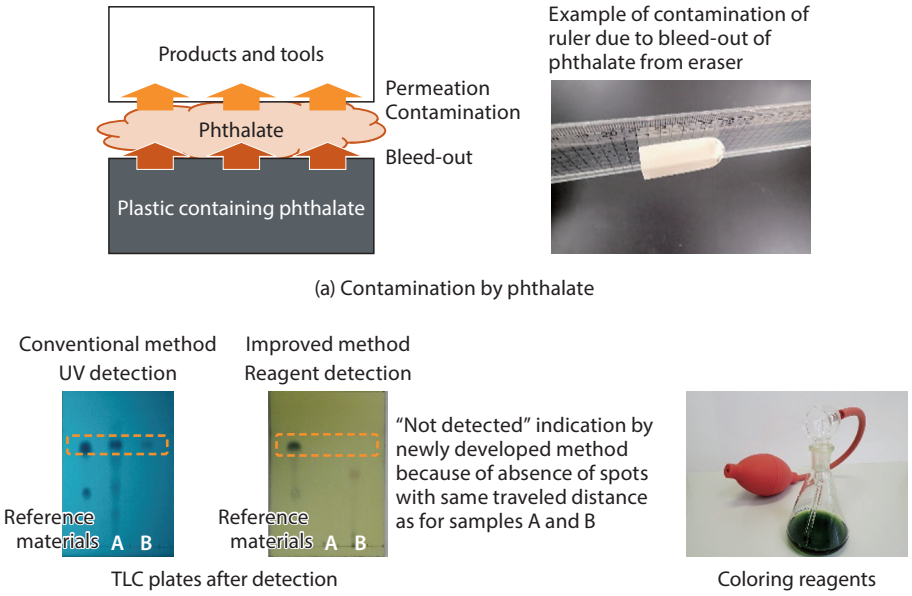
To facilitate lightning surge tests, Toshiba Corporation has visualized surge propagation paths and developed a quantitative evaluation technique using optically isolated probes that have recently become available. Because optically isolated probes provide a withstand voltage sufficiently higher than the lightning surge voltage, they allow analysis of the surge propagation path, making it possible to readily investigate the cause of an integrated circuit (IC) failure and to implement rational and efficient countermeasures. The newly developed technique also incorporates our technologies for high-frequency analog devices and printed circuit boards.

For example, since the outdoor unit of an air conditioner for building use has numerous cables, a lightning surge propagates through complicated paths. Excessive voltage is induced in a coil when part of the surge current flows through it. As a result, the power line voltage of a communication IC in its vicinity rises, damaging it.

Clarification of the surge propagation path enables appropriate selection and placement of surge absorbers. In addition, the optimal countermeasures can be selected by comparing the measured induced voltage with the absolute maximum rating of the communication IC.

(*) A lightning surge test standardized by the International Electrotechnical Commission (IEC) 61000-4-5, Japanese Electrotechnical Committee (JEC) 0103/0202, and other standards

1.19 Chemical Management Technology for Energy and Infrastructure Systems



Contamination caused by phthalates and simplified screening of phthalates by means of thin-layer chromatography (TLC) using coloring reagent

In 2015, the European Union (EU) amended the Restriction of Hazardous Substances (RoHS) Directive so as to impose restrictions on the use of four phthalates, which are primarily used as plasticizers, for electrical and electronic equipment sold in the EU. Although there were many RoHS exemptions, the exemption for industrial monitoring and control instruments (Category 9) expired in July 2021.

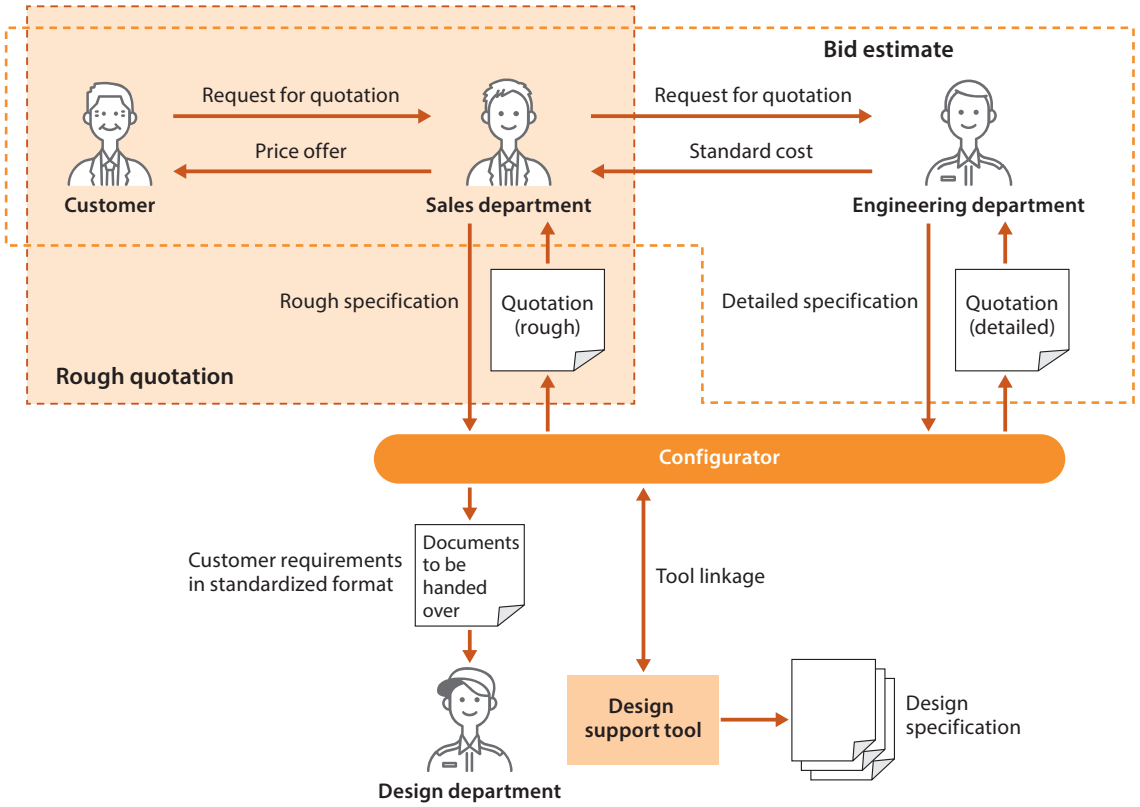
There is a risk that phthalates might bleed from plastic products and contaminate any objects that come into contact with them. Therefore, for proper management of the restricted substances, it is crucial to manage not only plastic products but also the tools and work mats used in manufacturing areas.

In 2018, Toshiba Corporation developed a simplified method for screening phthalates using thin-layer chromatography (TLC). However, as the application of TLC expanded, it encountered a problem of falsely detecting plastic additives as phthalates.

To solve this problem, we have developed a new variant of TLC using coloring reagents. The improved detection accuracy of the new method reduces the need for a precision chemical analysis to obtain a definitive conclusion.

Contamination by phthalates is affected by various factors, including temperature, contact time, and contact pressure. We verified the contamination phenomenon under manufacturing area conditions and identified an important factor related to the contamination speed. Based on this result, we have established a management system to minimize the risk posed by chemical substances.

1.20 Sales Configurator to Improve Operational Efficiency by Connecting Customer Requirements with Product Specifications



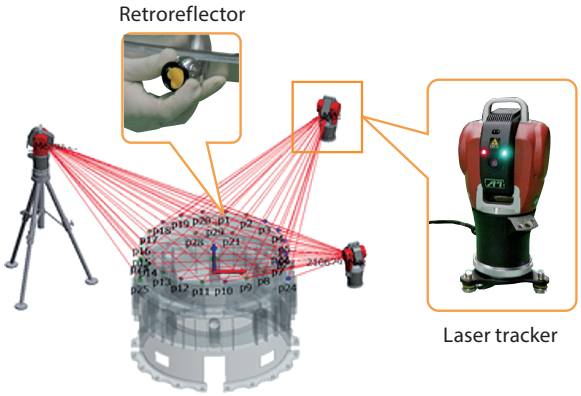
Flow of cost estimation of engineer-to-order products using sales configurator

For engineer-to-order products, it is important to swiftly offer attractive proposals that fully comply with customer requirements. However, for products with complex configurations, it is sometimes difficult to reconcile customer requirements with product specifications and costs, resulting in an iterative exchange of proposals and counterproposals until the customer is satisfied.

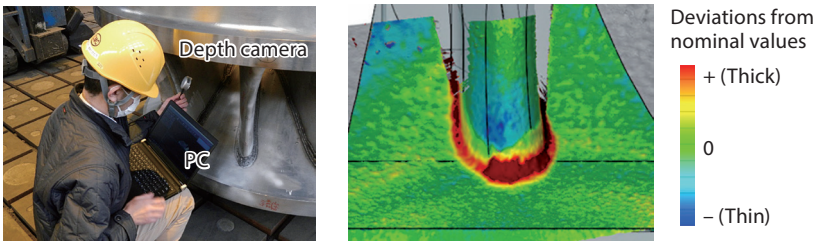
To solve this problem, Toshiba Corporation has developed a sales configurator that automatically generates quotations from customer requirements. This configurator prepares a list of standard customer requirements and possible variations based on the results of previous product development experience and trends in product specifications. Sales and engineering personnel can select customer requirements different from the standard requirements from this list to create a rough or bid estimate, facilitating the development of a quotation. In addition, the sales configurator has a function to generate a set of documents that an engineering department needs to hand over to a design department after receiving an order.

We have begun using the sales configurator for infrastructure systems and confirmed that it helps to reduce the time required for quotation and documentation.

1.21 3D Measurement Technology for Large Structures of Energy and Social Infrastructure Systems



3D measurement during installation process



Measurement during manufacturing process

Visualization of deviations from nominal values

Examples of application of newly developed 3D measurement technology

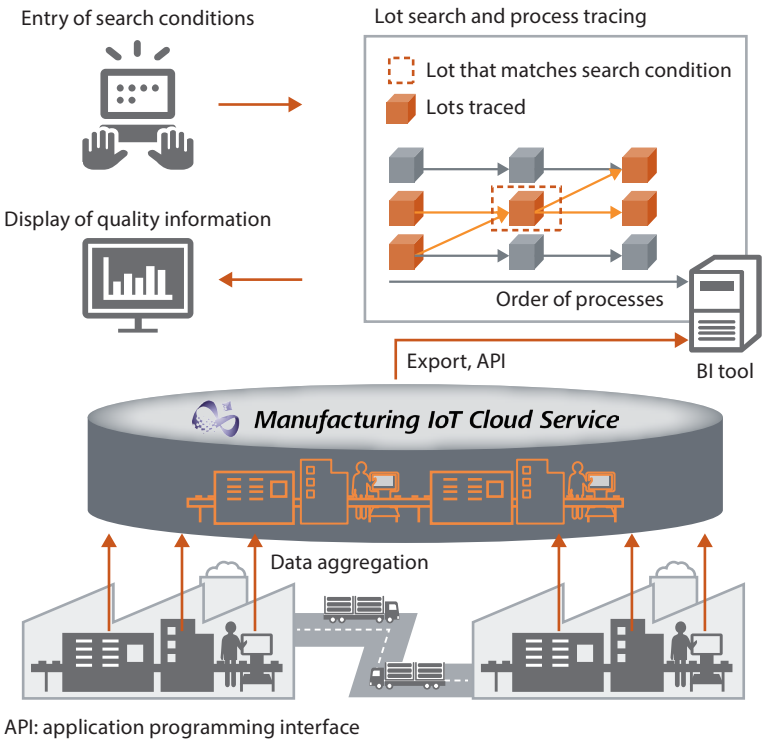
To ensure that large power generation systems work as they are designed to, the accuracy of installation and the machining precision of key components are crucial. It is therefore essential to accurately measure a system's 3D geometries.

For system installation, skilled workers are required to measure lengths and dimensions using manual tools. Toshiba Corporation has developed a technology to evaluate installation accuracy by combining 3D measurements using a portable laser tracker and a data integration technique. In the future, we will also use the newly developed technology to improve the efficiency of the assembly process and maintenance work.

In the field of component manufacturing, costly specialized measuring instruments are required to evaluate the machining accuracy of complex 3D components. Furthermore, post-processing procedures to display the evaluation results are time-consuming.

To solve these issues, the newly developed technology uses an inexpensive depth camera to capture 3D data and visualizes their differences from design data. The new technology also incorporates a system that enables quick decisions for corrective machining. We will deploy this system for 3D inspection in various fields since it allows the evaluation of machining accuracy during the manufacturing process.

1.22 Automation of Traceability Management for High-Mix Low-Volume Production Using Manufacturing Internet of Things Platform



Overview of traceability management using manufacturing IoT platform

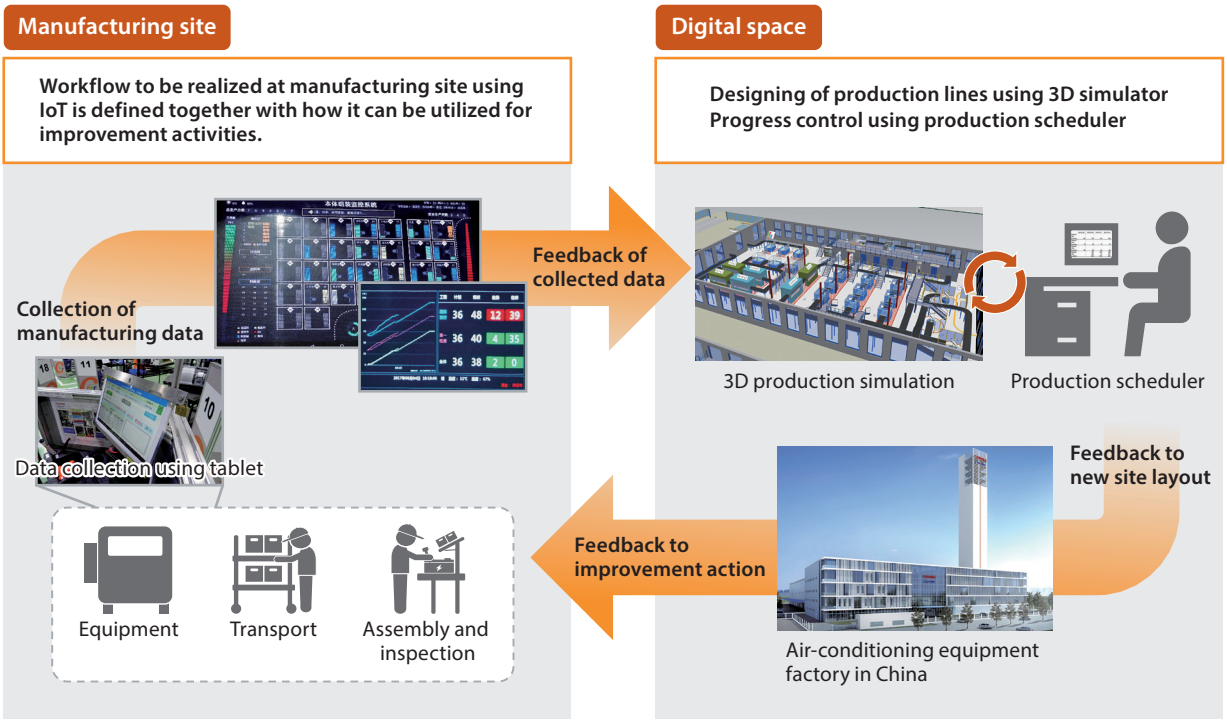
To enhance customer satisfaction, it is crucial to stably provide products that meet customer requirements. High-mix low-volume production requires complicated quality control because it involves frequent changes to the manufacturing processes and materials.

To resolve this issue, Toshiba Corporation has developed a quality information retrieval system that facilitates traceability management even for products whose manufacturing processes are divided across multiple factories. This quality information retrieval system uses the Manufacturing IoT Cloud Service from Toshiba Digital Solutions Corporation to associate manufacturing lot records with Internet-of-Things (IoT) data. The associated data are imported into business intelligence (BI) tools to make it possible to retrieve information about target lots under various search conditions such as the type of equipment or time period.

The new system can also trace information about the division and integration of the retrieved lots to identify lots that might be affected in other processes. In the event of quality deterioration, the new system compares the retrieved lots with other lots to assist in identification of the affected lots, equipment, and processes, thereby expediting investigation of the causes and quality improvement activities.

In the future, we will implement traceability management across overseas factories and suppliers to contribute to further quality improvement.

1.23 Technology to Evaluate Production Line Design Using 3D Data



Example of application of technologies for design and evaluation of production lines to overseas manufacturing site

Toshiba Corporation has been developing solutions for the IoT networking of manufacturing sites, including those for the acquisition of production progress and other manufacturing data, evaluation of the design and operation of production lines using a 3D production simulator, and improvement of production management efficiency using a production scheduler.

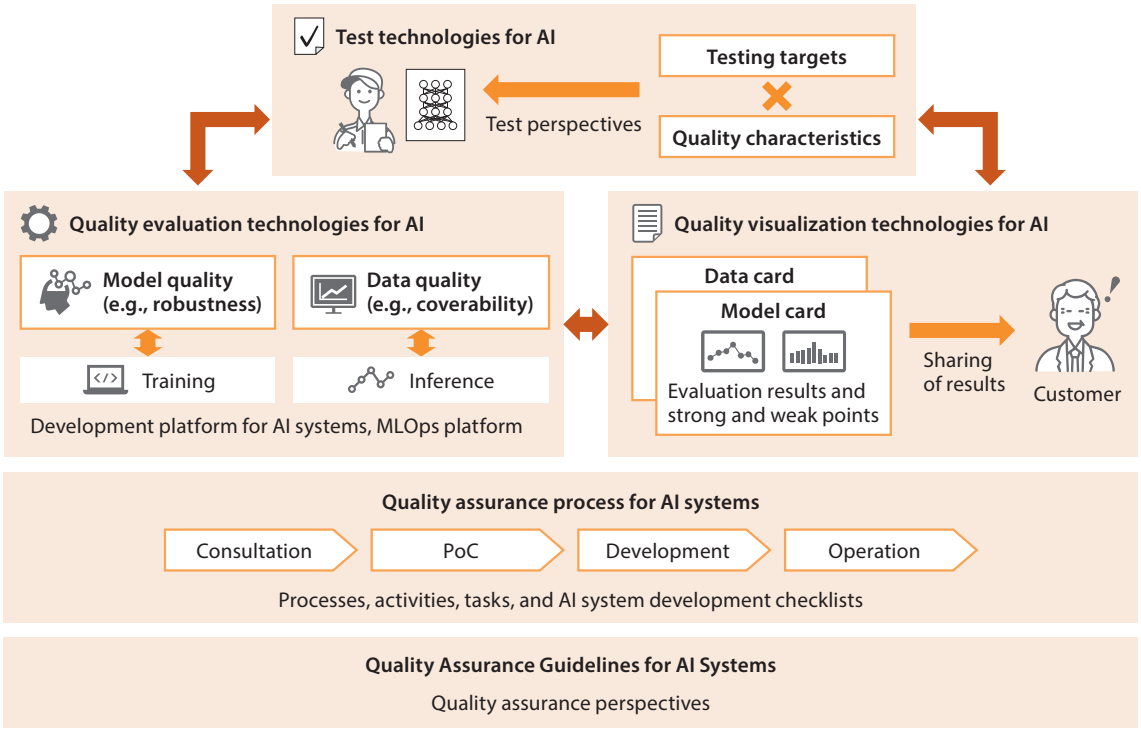
To avoid pursuing myopic optimization and achieve effective implementation of IoT solutions, it is crucial to maintain a comprehensive vision for data utilization and align the timing, location, and means of data acquisition. Therefore, we defined in advance the manufacturing workflow to be realized using IoT together with how it could be utilized for improvement activities, allowing us to develop a series of solutions using centralized data.

We introduced a manufacturing data acquisition system using tablets at an air-conditioning equipment factory in China to achieve efficient data acquisition and tabulation without placing an extra burden on the workers. We also connected these data with a 3D production simulator to create a digital space environment for the verification of production line layout and production quantities. As a result of preliminary layout verification, production lines were relocated to a new building without any delay. After the new building came online, we were able to review production and personnel plans and explore improvement measures in advance, thereby efficiently fulfilling the production plan.

Furthermore, we applied the operating rules for production lines and production capacity data verified by simulation to the scheduler in order to establish a production control mechanism. Since production plans can be created quickly and without any additional workload or specific expertise, managers can now concentrate on considering improvement actions according to the progress of manufacturing.

As a result of these efforts, we have succeeded in creating a system that links data acquisition, production line verification, plan management, and improvement implementation. This enables efficient improvement activities without increasing work hours even when the production scale needs to be expanded. We will continue to accelerate the introduction of IoT at our manufacturing sites.

1.24 Quality Assurance Processes and Evaluation Technologies for AI Systems



PoC: proof of concept
MLOps: machine learning operations

Quality assurance processes and evaluation technologies for AI systems

The development of AI systems has been accelerating in recent years. AI systems incorporate models that are trained by learning a large quantity of data. When given an unknown input, the AI model generates an indefinite output, which makes it extremely difficult to assure the quality of AI systems. It is also necessary to consider various characteristics unique to AI models, including robustness in diverse environments, coverability and uniformity of datasets, and explainability of AI models.

Toshiba Corporation has been studying methods to assure the quality of AI systems and has now formulated the Quality Assurance Guidelines for AI Systems, comprising a set of guidelines that summarize several perspectives on quality assurance. For the quality assurance of AI systems based on these guidelines, we have established the following four processes and developed quality evaluation technologies:

(1) Quality assurance process for AI systems

This process stipulates quality assurance activities and deliverables for AI system development, incorporating activities unique to AI system development (e.g., data analysis and AI model evaluation) into traditional software development processes. We have also created a quality checklist for evaluating the quality of AI systems.

(2) Method of visualizing the quality of AI systems

Since it is difficult for non-engineers to understand the technical details of AI, we have created Quality Cards, a set of formats that allows AI developers to summarize the specifications for training data and the results of AI model evaluation. The Quality Cards make it easier to communicate the performance of AI systems to our customers both qualitatively and quantitatively.

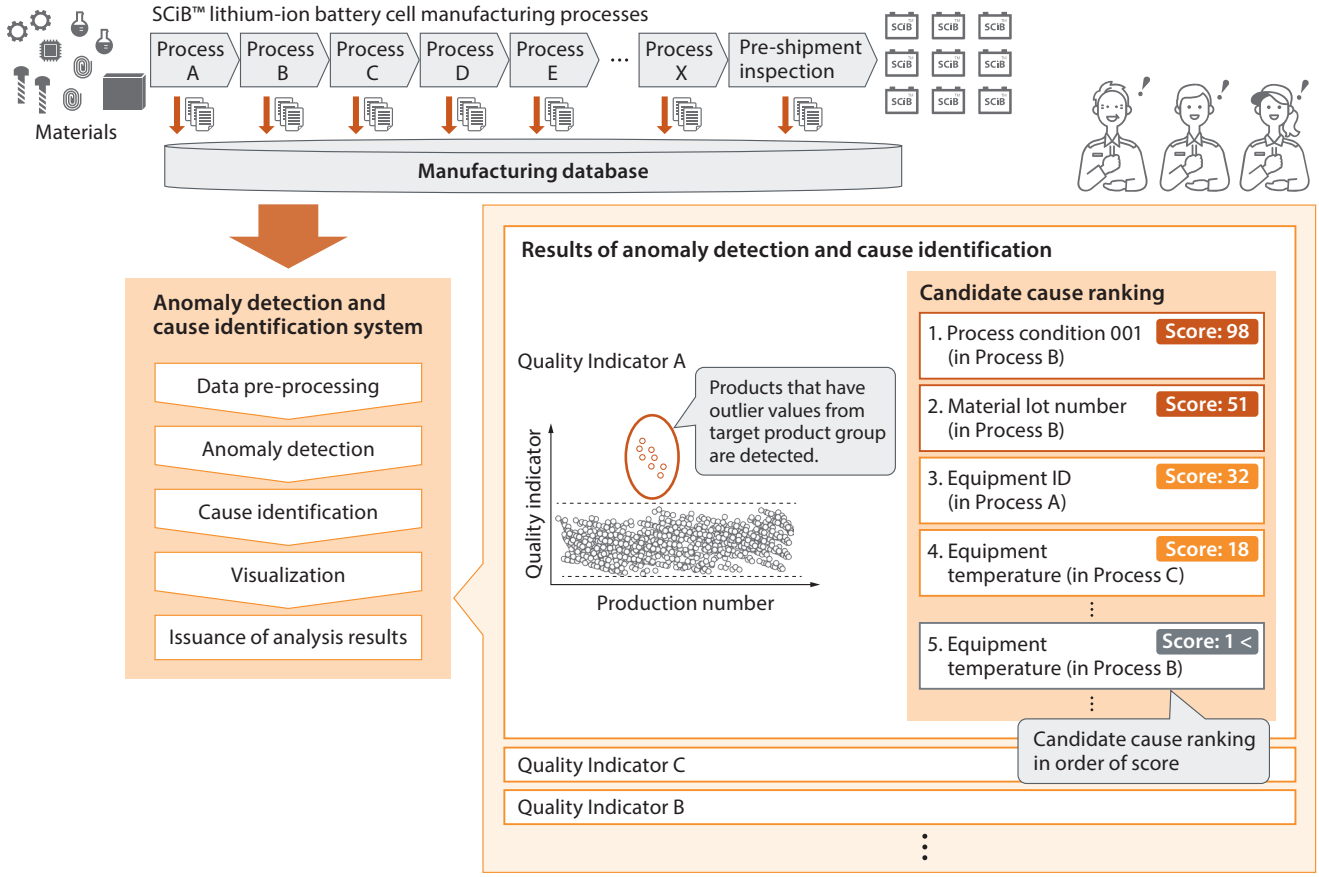
(3) AI Testing Guidelines

These guidelines cover all the perspectives for the testing of AI systems. It is necessary not only to determine whether an AI system satisfies its requirements and specifications but also to include AI-specific test perspectives such as data and models in testing. The AI Testing Guidelines contain all test perspectives, covering combinations of testing targets and quality characteristics.

(4) AI quality evaluation toolkit

This toolkit makes it possible to quantitatively evaluate the robustness of AI models and the coverage of training datasets.

1.25 Anomaly Detection and Cause Identification System for SCiB™ Lithium-Ion Battery Cell Manufacturing Processes



Outline of anomaly detection and cause identification system for SCiB™ lithium-ion battery cell manufacturing processes

Demand for rechargeable lithium-ion batteries (LIBs) has been increasing in recent years, particularly in the fields of automotive and industrial equipment. Toshiba Corporation monitors and stores various manufacturing data at the SCiB™ LIB production facility of Kashiwazaki Operations to maintain high yields. These manufacturing data make it possible to prevent process failures and improve the productivity at the production facility. However, to achieve exhaustive data monitoring, we needed efficient systems that do not rely on experts because the manufacturing data will continue to increase as we expand our production.

Under these circumstances, we have developed an anomaly detection and cause identification system for SCiB™ LIB cell manufacturing processes that automatically detects anomalous data and identifies candidate causes of the anomaly, ranking their probability in descending order. This makes it possible for even a non-expert to quickly determine the cause of an anomaly by investigating the candidate causes according to their order of probability.

The features of the new system include the following:

(1) The manufacturing data from all processes are consolidated to achieve traceability. For example, the data collected from the electrode manufacturing, cell assembly, and pre-shipment inspection processes are linked together.

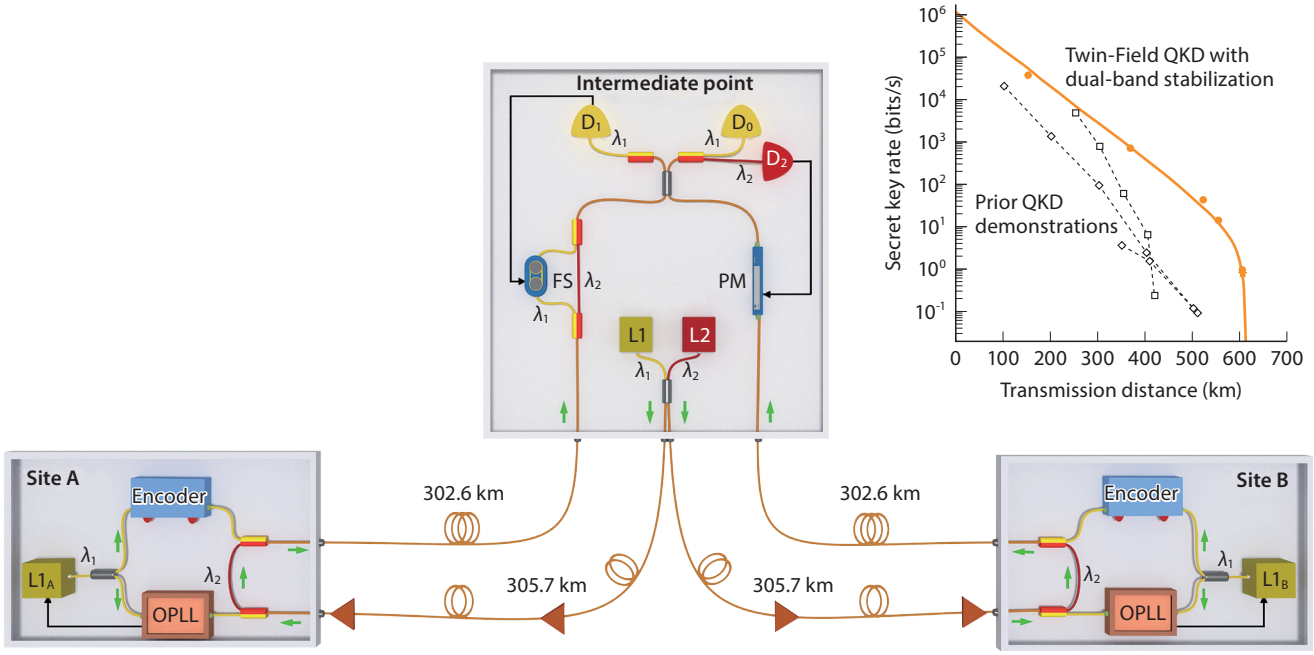
(2) Anomalous manufacturing data are detected automatically(*). For example, outliers that could be a sign of process failure are detected as anomalies.

(3) The causes of an anomaly are identified based on the data from each process. For example, if, in parallel processes, the anomaly occurrence rate of a specific process is higher than those of the other processes, the statistical accuracy of the deviation is evaluated using a framework of hypothesis testing. Accuracy is calculated as scores of the probability of the cause.

As a result of testing at Kashiwazaki Operations, we confirmed that the new anomaly detection and cause identification system requires only 1/200th of the time needed by a manual investigation. We will commence the use of this system at Kashiwazaki Operations in FY2022.

(*) The newly developed system can also identify causes for the occurrence of defective cells in manufacturing processes, making it useful for investigations into the cause of such problems.

1.26 Quantum Communications over Optical Fiber Exceeding 600 km in Length



D: detector FS: stabilizing fiber stretcher PM: stabilizing phase modulator L: laser λ: wavelength OPLL: optical phase-locked loop

Setup of demonstration experiments on quantum communication over optical fibers exceeding 600 km in length and quantum key distribution performance

Quantum key distribution (QKD) is a promising technology for securing digital communications as it offers a way to distribute keys used for data encryption (encryption keys) that are secure against any attacker, including an attacker equipped with a quantum computer.

In QKD, the generation of encryption keys is based on the transmission of quantum bits, or qubits, with information often encoded in the phase of photons. The encoded photons are then transmitted along a communication line, often an optical fiber. Unavoidable changes in the ambient conditions cause the expansion and contraction of fibers used to transmit the qubits, which scramble the encoded information. This poses a major practical challenge for realizing long-distance QKD.

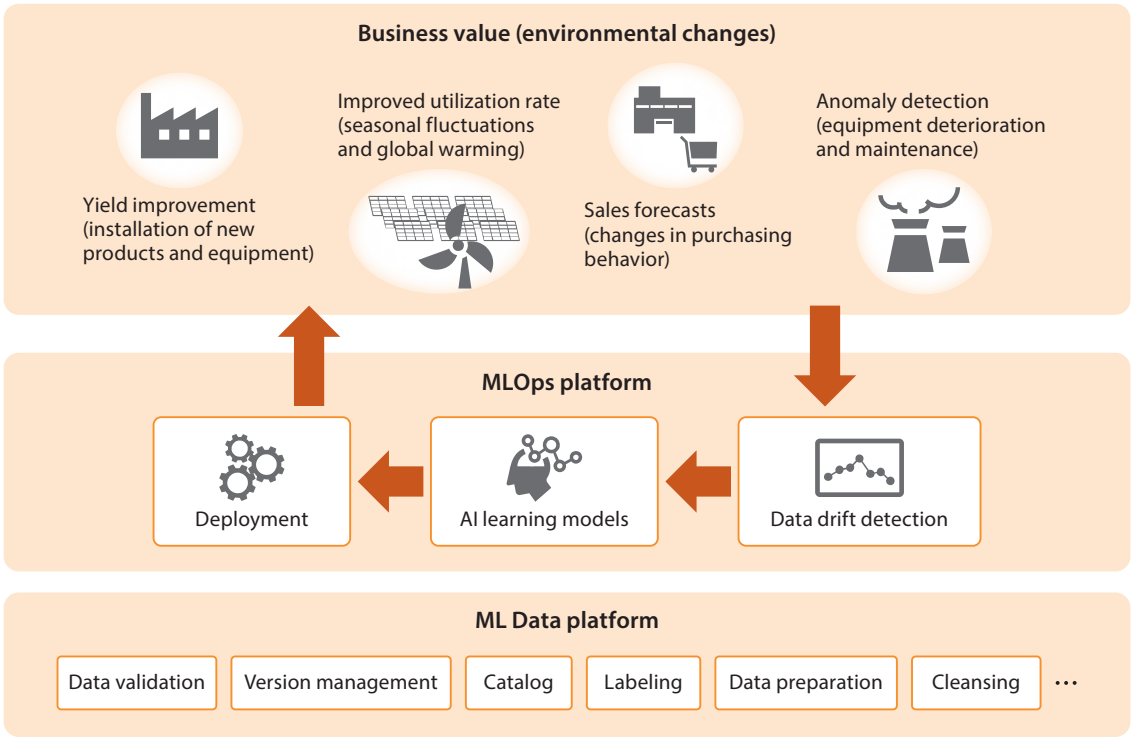
To solve this problem, Toshiba Europe Limited has developed a new technique called dual-band stabilization. This stabilization method introduces a reference signal at an additional wavelength to that of the QKD signal, which realizes a fast feedback system acting on both wavelengths in addition to the slow system acting only on the QKD wavelength. Our newly developed method is capable of holding the optical phase of a quantum signal constant to within a fraction of a wavelength even after propagation through hundreds of kilometers of fiber.

By applying dual-band stabilization to Twin-Field QKD, which is our original protocol for long-distance QKD, we achieved higher key rates and longer distances than any previous fiber-based QKD experiment, and succeeded in implementing a secure quantum communication beyond the barriers of 600 km and 100 dB loss. We confirmed a key rate of 1 bit/s for 600 km communication and 40 bits/s for the previous record distance of 500 km communication. This result is the longest fiber-based QKD on record(*). Our new technology will reduce the number of transmitting/receiving stations, which require strong security, and enable efficient building of long-distance secure communication between cities and countries.

This work was partially funded by the EU through the H2020 project, OpenQKD.

(*) As of June 2021 (as researched by Toshiba Europe Limited)

1.27 MLOps Platform to Provide High-Quality AI Services



ML: machine learning

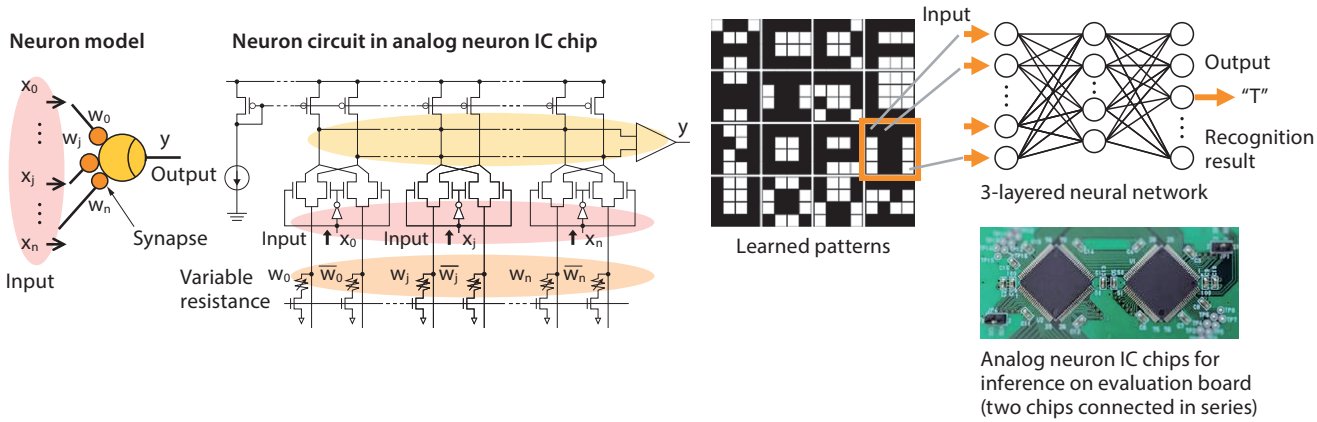
Overview of features provided by machine learning operations (MLOps) platform

The prediction accuracy of AI services is susceptible to environmental changes, seasonal fluctuations, equipment deterioration, and changes in customers' purchasing behavior. To maintain the quality of AI services, it is essential to monitor both prediction accuracy and data drift. In the event of a reduction in prediction accuracy or the occurrence of data drift, an AI model must be retrained and redeployed.

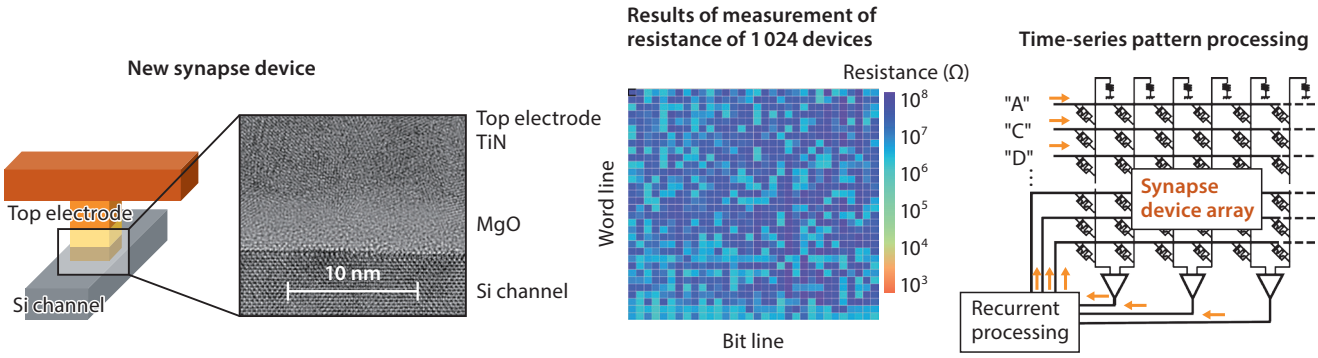
To sustain value provision even in the face of changes in the external environment and business requirements, Toshiba Corporation has developed a machine learning operations (MLOps) platform and commenced its deployment throughout the Toshiba Group. This MLOps platform incorporates technologies to monitor data drift and automate the training and deployment of AI models, making it possible to semi-automate the life cycle of AI models from development to operation.

In the future, we will release a data platform for managing training data, which will allow AI, information technology (IT), and service engineers to work closely to continuously provide high-quality AI services for customers.

1.28 Development of Analog Neuron IC Chip for Inference and Its Synapse Devices



IC chip with analog neuron circuits modeled on biological neurons and its neural network recognition application



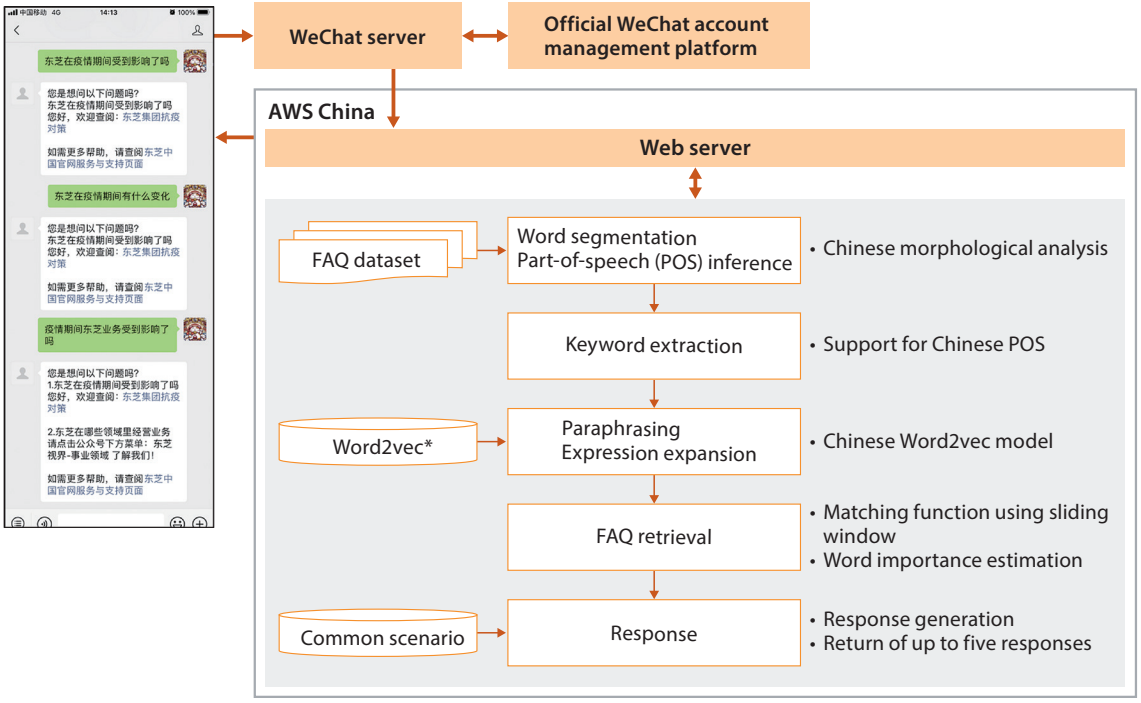
Newly developed synapse device, measured resistance of synapse device array, and time-series pattern processing

Toshiba Corporation has developed an analog neuron IC chip for inference, which performs neural network (NN) operations modeled on the biological brain and neurons. We connected multiple instances of this IC in series to configure a three-layer NN for a demonstration of small-scale pattern recognition operation, and confirmed that it can recognize patterns correctly and output the corresponding electrical signals. The NN operating speed per unit power consumption was more than 10 times faster than that of a software program on a commercial microcontroller. The use of the analog neuron IC chip in edge devices will make it possible to realize high-speed abnormality detection as well as predictive failure detection of the edge devices using information from on-site sensors with ultralow power consumption.

Since the power consumption of the newly developed analog neuron IC chip is determined by the current flowing through the synapse devices, a further reduction in power consumption can be expected by using high-resistance electronic devices for low-current operation. In addition, the circuit integration level can be increased by using such synapse devices in crossbar or crosspoint arrays.

Therefore, we have developed a synapse device with a thin-film multilayer structure consisting of titanium nitride (TiN), magnesium oxide (MgO), and Si layers, and have confirmed that its current-voltage characteristics show a clear diode effect, variable resistance, and low-current operation. The prototype chip has an array structure of 32 inputs by 32 outputs. Even though about 1 000 synapse devices are connected, the resistance of each synapse device can be read out independently because of their intrinsic diode effect. The addition of these connections also opens up the possibility of recurrent NN applications in array structures. We believe that further technological development at the device level to replicate the workings of the brain will provide a promising future for edge AI devices.

1.29 Implementation of Automated Chinese-Language Scenarioless Dialogue FAQ System in WeChat Account



AWS: Amazon Web Services

* A natural language processing technique in which words in a sentence are converted into a list of numbers called vectors to denote the semantic and syntactic relationships among the words

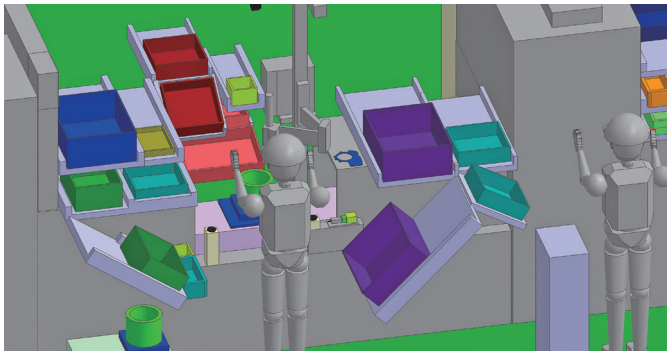
Overview of automated Chinese-language scenarioless dialogue FAQ system

Many Chinese companies are actively using WeChat, the most popular Chinese social networking service (SNS), to conduct public relations campaigns. With this as a background, Toshiba (China) Co., Ltd. has developed a Chinese-language scenarioless dialogue system for frequently asked questions (FAQs) and implemented it in its official WeChat account to support automated replies to incoming inquiries from general users.

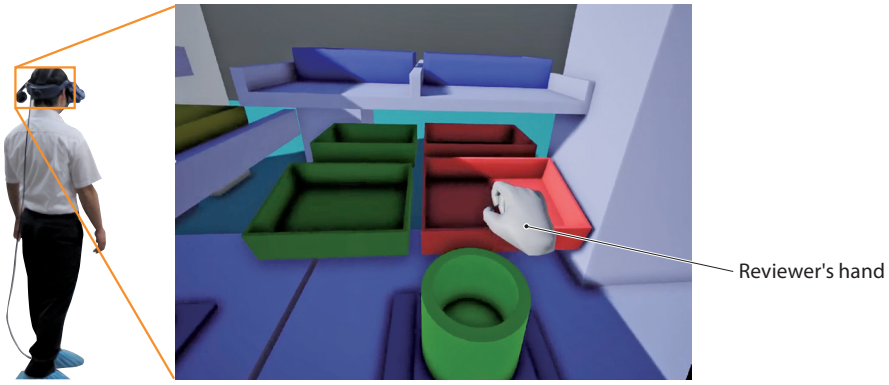
Based on the Japanese-language version of the engine, which is capable of building a chatbot system only from a FAQ dataset, we added several new functions such as Chinese morphological analysis, keyword extraction, paraphrasing, and other features specific to the Chinese language. In addition, we developed a sliding-window matching function for technical terms to improve response accuracy.

Our WeChat account received approximately 1 800 inquiries about the Chinese business of the Toshiba Group between April and September 2021. The newly developed dialogue FAQ system automatically replied to these inquiries with high accuracy (task achievement rate: 93.6%), significantly contributing to an improvement in the work efficiency of our public relations representatives. In the future, we will consider expanding its use to other group companies in China.

1.30 VR Technology to Improve Efficiency of Design Reviews of Production Lines



(a) 3D model data (simplified model)



(b) VR design review

Design review with VR tools using 3D model data for construction of production line

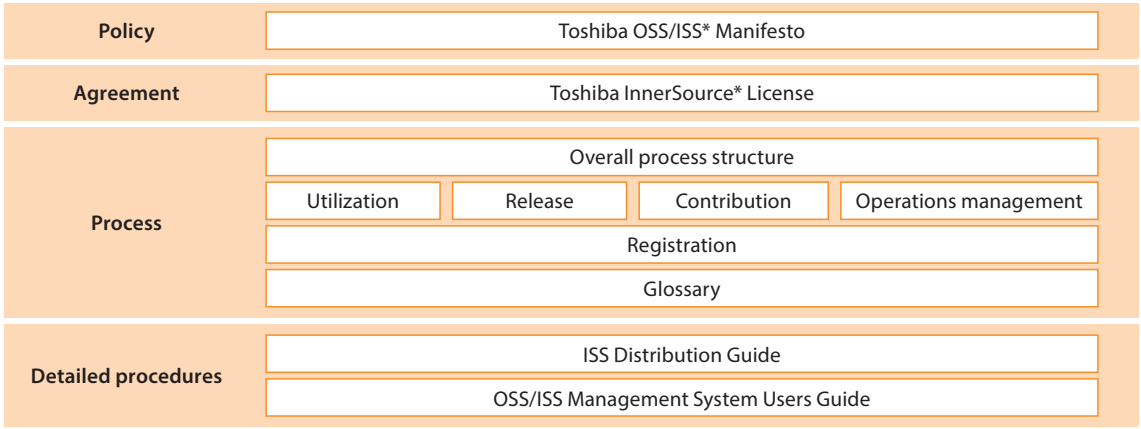
In the design of a production line, a design review is conducted using drawings and 3D models. However, if the production line designers themselves lead the design review, they might end up iterating the design cycle because of insufficient workability checks from the perspective of production line workers.

To solve this problem, Toshiba Corporation has developed a virtual reality (VR) technology for production line design reviews. The newly developed VR technology minimizes the details of 3D model data to eliminate delays between a participant's motion and the corresponding response of the virtual scene. This creates a feeling of immersion and allows design reviewers to check the equipment layout and the workability of each process as if they were on the physical production line.

In addition, the new VR technology allows design reviewers to recognize their hand positions in the virtual environment and to modify the 3D model on the spot.

We employed the new VR technology in a design review for the development of a mass-production line. As a result, we succeeded in modifying the position where workpieces are discharged from a given system, prior to the actual construction of the production line. It would have been difficult to resolve this issue without VR technology.

1.31 Development of Overall Processes and Training System to Ensure Compliance with OSS Licenses



(a) Overall processes

Course	Main topics	Target audience	Difficulty	Style
Beginners'	Basic knowledge of and considerations for OSS	Software users	General topics	E-learning
Basic	Utilization and considerations as per Toshiba Process	Software engineers and quality assurance, intellectual property, and legal affairs personnel	Partially professional	
Advanced	Contribution to OSS and OSS auditing procedures	Software engineers	Professional	
Expert	Acquisition of specific practical methods	Software engineers	Professional	Hands-on

(b) Training system

* ISS: InnerSource software. Software developed within an organization using an open-source software development style (i.e., InnerSource development style).

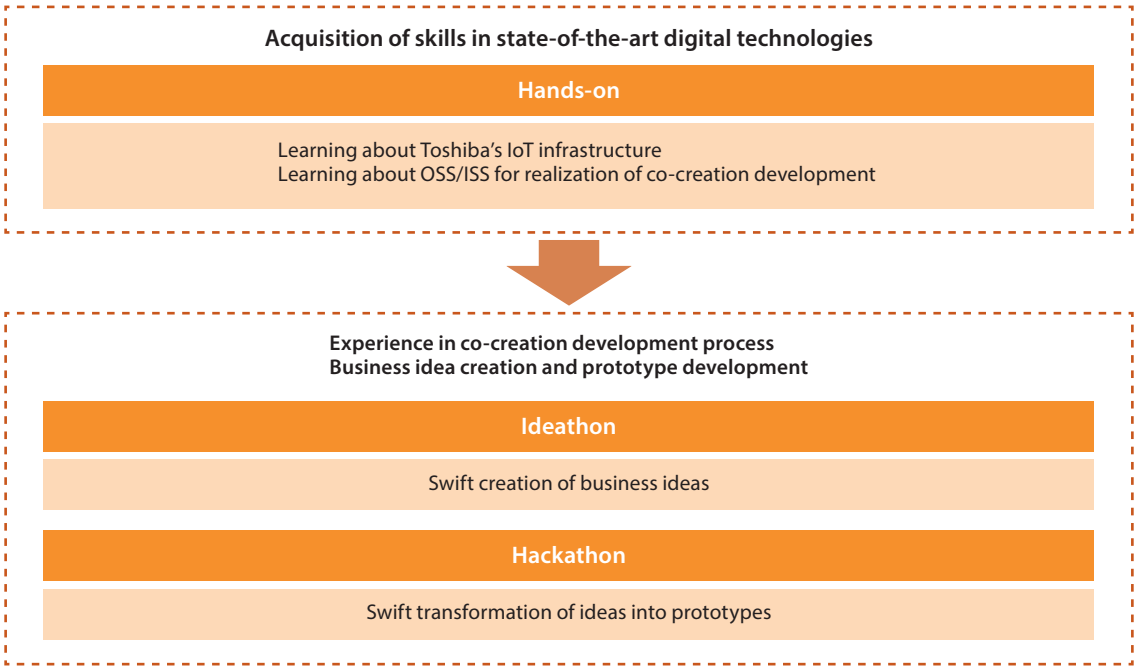
Overall processes for utilization of and training system for OSS in Toshiba Group

To ensure compliance with open-source software (OSS) licenses and obtain certification under the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 5230:2020 standard, "Information technology — OpenChain Specification," Toshiba Corporation has been creating and expanding its overall processes and training system for OSS. In 2020, we formulated the OSS Manifesto as a policy for the use of OSS in the Toshiba Group. Our overall processes and training system for OSS are designed based on the OSS Manifesto for efficient and appropriate use of OSS.

The OSS training system consists of beginners', basic, advanced, and expert courses. The beginners' course started in July 2021, and about 17 000 employees had completed it by October 31 of the same year. Not only software engineers but also officers and employees from a wide range of backgrounds took the course, including salespeople, sales engineers, and those from the quality assurance, procurement, intellectual property, and legal affairs departments.

To date, we have widely disseminated basic knowledge of OSS. Our next step is to start other courses to ensure OSS license compliance with the aim of obtaining certification under ISO/IEC 5230:2020 throughout the Toshiba Group.

1.32 Output-Oriented Training for Co-creation and Digital Human Resource Development



Outline of output-oriented training for co-creation and digital human resource development in Toshiba Group

The key to success in co-creating new value with customers lies in quickly transforming ideas into prototypes through the implementation of collaborative and cooperative work with customers and obtaining customer and market feedback through repeated trial and error. However, engineers involved in conventional development have long been required to deliver quality products efficiently and without any failure. Therefore, they need to learn new development styles and mindsets in order to acclimate themselves to co-creation type development.

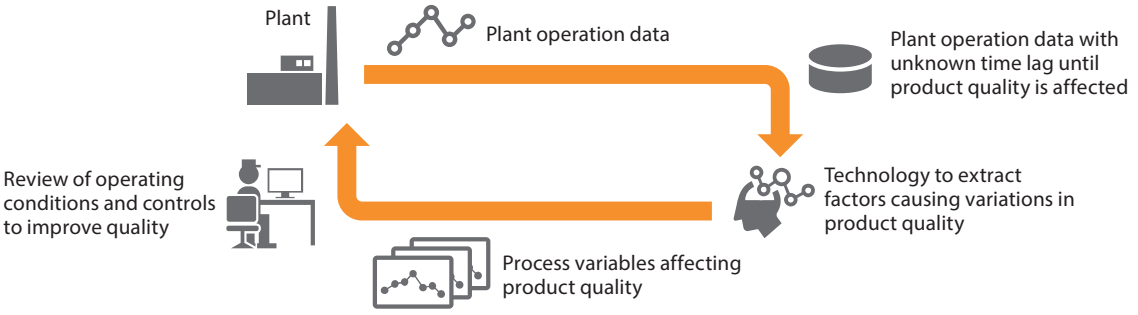
Under these circumstances, Toshiba Corporation has developed and conducted a training program on co-creation. In this training program, participants learn about Toshiba's IoT infrastructure services and OSS/ISS(*), which are designed for the realization of co-creation development, so that they can acquire the skills necessary to create business ideas and transform them into prototypes.

Participants engaged in a wide range of businesses in the Toshiba Group are divided into teams to actualize their ideas as prototypes using state-of-the-art digital technologies. They are encouraged to improve their skills in creation, thinking, problem-solving, and communication.

Through this training, we will continue to develop core human resources for co-creation development in the Toshiba Group.

(*) OSS/ISS: open-source software/InnerSource software

1.33 Technology to Extract Factors Causing Variations in Product Quality from Plant Operation Data



Outline of technology to extract factors causing variations in product quality from plant operation data

Example of PLANETMEISTER™ real-time process data management system display to construct regression model elucidating quality variation factors

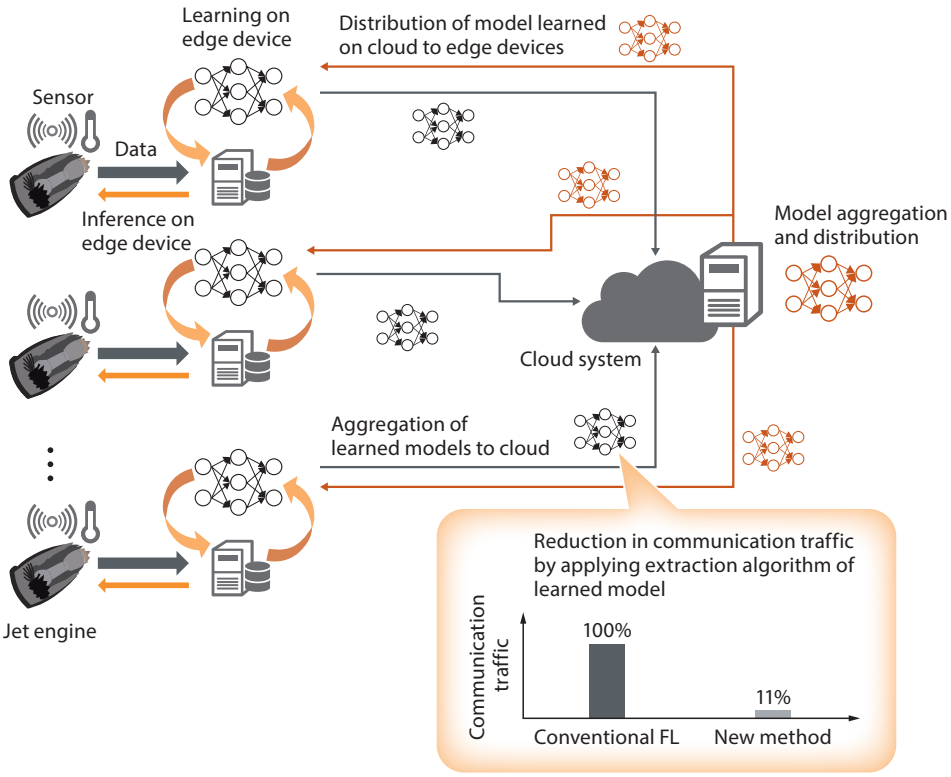
Plant operation data that are collected daily in chemical, steel, and other process industries potentially contain a great deal of information that could help to improve the quality of the processed products. Toshiba Corporation has developed a method to automatically extract quality-affecting factors from plant operation data using sparse modeling techniques for automatic variable selection.

In process industries, there is a time lag until the operating state of an individual piece of equipment begins to affect the quality of the processed products. This makes it difficult to identify quality-related factors. The newly developed method performs variable selection in order to choose the best subset of predictors to identify the factors that could cause significant variations in quality exceeding control limits, even with a time lag.

We are planning to use the new method to build a regression model that elucidates quality variations and to incorporate a quality variation prediction function based on it into PLANETMEISTER™, a real-time plant information management system from Toshiba Mitsubishi-Electric Industrial Systems Corporation (TMEIC).

We will continue to develop methods for updating the model in a stable and efficient manner.

1.34 IoT Platform Using Federated Learning



Overview of operation of IoT platform using federated learning (FL)

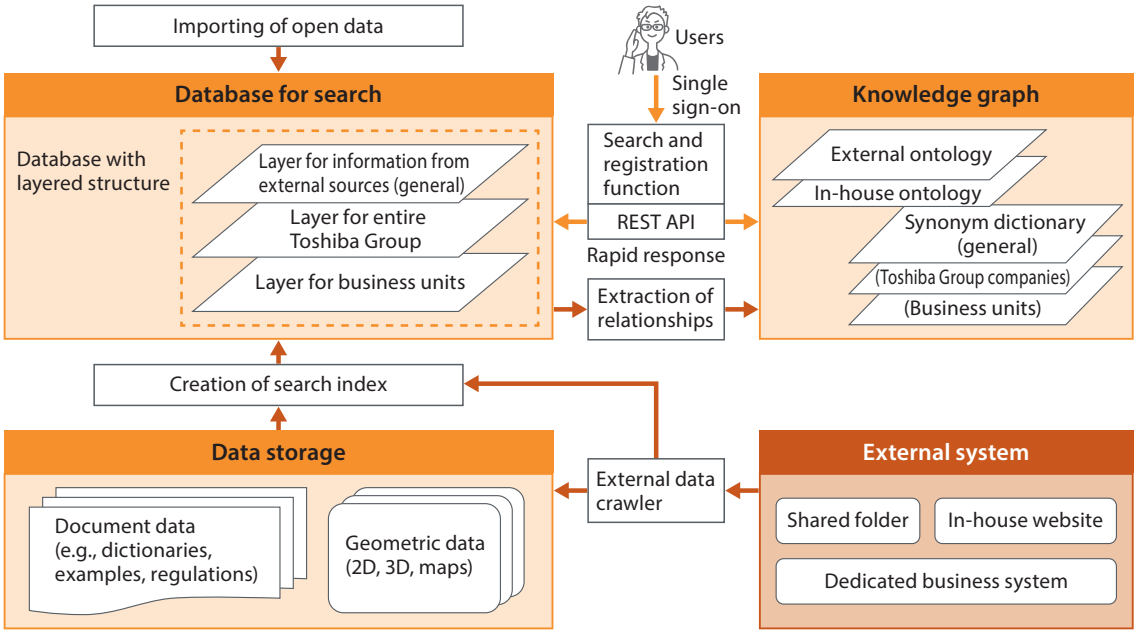
Federated learning (FL) is a machine learning technique that trains a model across multiple distributed edge devices without aggregating data to a cloud system. The central server on the cloud aggregates only the learned models. Since FL does not transmit raw data, it provides the benefits of data security and reduced communication traffic.

However, the size of the machine learning models that the manufacturing and commerce industries have on large IoT platforms is increasing in proportion to the volume of data. It is therefore necessary to further reduce the communication traffic required to transmit FL models.

To reduce the size of FL models, Toshiba Europe Limited has developed a new algorithm that observes the status and frequency of model updates on edge devices and minimizes the size of the models to be aggregated. In a proof-of-concept (PoC) demonstration of anomaly detection in aircraft jet engines, the new algorithm provided an 89% reduction in communication traffic in comparison with the conventional FL while maintaining the same accuracy as centralized learning.

We plan to use this platform for factory and plant applications as a solution to relax the requirements for communication between edge devices and the cloud.

1.35 Quick and Secure Search Engine System for Enterprise-Wide Knowledge Management



API: application programming interface

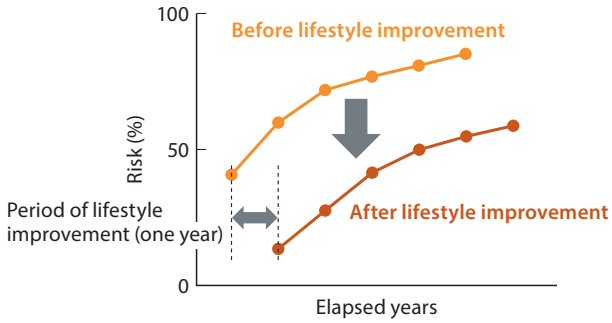
Architecture of quick knowledge search system in Toshiba Group

Toshiba Corporation has developed a knowledge search system for enterprise-wide knowledge management to share the technical knowledge and expertise of the Toshiba Group throughout the entire company, so as to facilitate efforts to enhance customer value and fundamental earning power. This knowledge search system allows us to share not only textual information such as in-house dictionaries, casebooks, and regulations but also two-dimensional (2D) and 3D images and maps necessary for the creation of various documents. New information can be registered by users or imported by system administrators from internal and external sources. The newly developed knowledge search system is highly convenient and features rapid response. In addition, it uses a layered database structure to control users' access rights and thereby ensure data security. A column store database and representational state transfer (REST) are used to reduce client traffic, making it possible for the search engine to search more than 20 million contents in one second or less. Because of the layered database structure, the new knowledge search system achieves both browsing control and rapid bulk search.

To allow the sharing of technical knowledge of the Toshiba Group, we have redefined the disclosure range and established internal rules. In addition, the new knowledge search system uses the functions of the operating system and cloud managed services to satisfy system requirements for single sign-on convenience, redundancy, and availability, simplifying system maintenance.

1.36 Lifestyle Improvement AI Solution Using Data Collected in Health Examinations

Item	Before lifestyle improvement	After lifestyle improvement
Gender	Male	Male
Age	54	55
Weight (kg)	73	67
Systolic blood pressure (mmHg)	97	95
HbA1c (%)	6.4	6.3
Frequency of drinking	Every day	Does not drink
Exercise	No	Two or three times per week



HbA1c: hemoglobin A1c

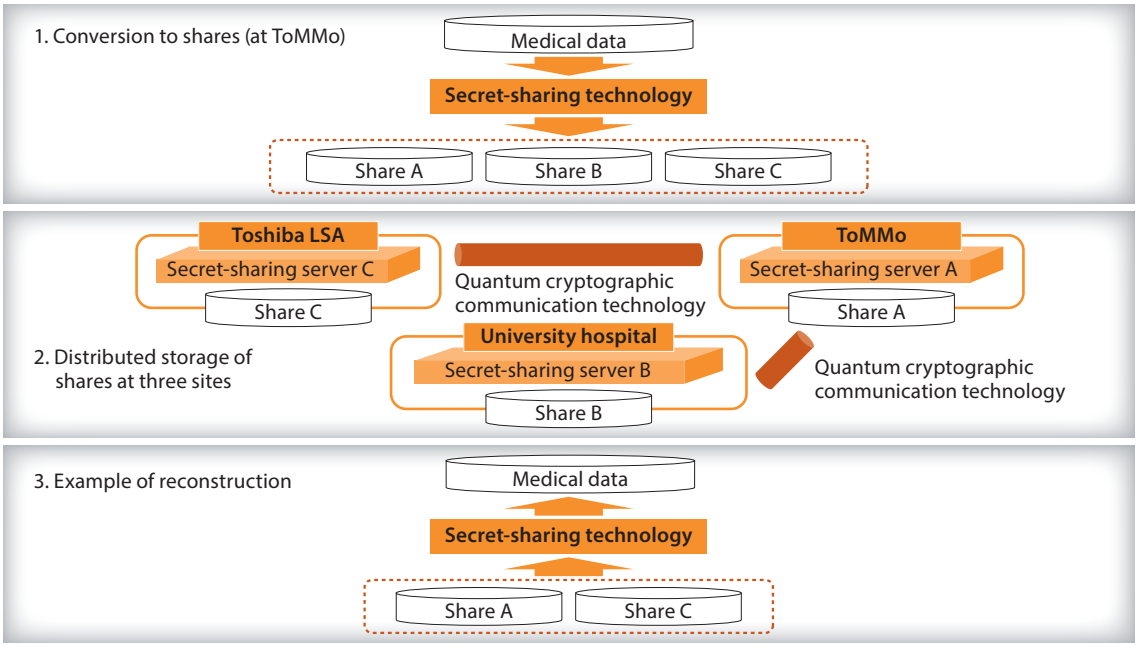
Example of effectiveness of lifestyle improvement AI solution

Rising medical costs and patients' declining quality of life (QOL) have become issues in Japan accompanying the increase in the number of patients suffering from lifestyle-related diseases. A disease risk prediction AI solution previously developed by Toshiba Corporation can identify people at high risk of contracting diseases. As a next step, there was a need for a solution to reduce the disease risk.

The weight loss achievable through lifestyle improvements and the resulting improvement in biometric values differ greatly depending on the individual's level of risk associated with metabolic syndrome (suffering from, candidate for, or free of metabolic syndrome). We have now developed a lifestyle improvement AI solution by combining knowledge of metabolic syndrome and the disease risk prediction AI solution. The newly developed AI solution offers recommendations about lifestyle improvement according to the risk reduction target and health examination data, including biometric values and the results of medical interviews. There are 11 recommendations concerning lifestyles such as exercise habits, eating dinner at a late hour, and drinking habits.

We are planning to add genomic data and develop AI solutions that take individuals' constitutional predispositions into consideration.

1.37 Distributed Storage of Genome Analysis Data Using Quantum Cryptographic Communication and Secret-Sharing Technologies



Toshiba LSA: Toshiba Life Science Analysis Center
University hospital: Tohoku University Hospital
ToMMo: Tohoku University Tohoku Medical Megabank Organization

Overview of genome analysis data distributed storage system at three sites in Sendai City, Japan

With security protection becoming increasingly crucial, cybersecurity is also progressing in the field of medical services. To ensure the safe storage of sensitive data, Toshiba Corporation, the National Institute of Information and Communications Technology (NICT), and Tohoku University have developed a distributed storage technology that combines (1) a quantum cryptographic communication technology comprising a method of secure communication based on the principle of quantum mechanics, and (2) a secret-sharing technology that realizes secure data storage by splitting original data, or a secret, into multiple fragments of meaningless data called shares. The group has demonstrated the ability of the newly developed technology to back up bulk genome analysis data.

For distributed storage, the genome analysis data were divided into three shares, which were distributed among three sites. The secret can be reconstructed only when a sufficient number of shares are combined. For the demonstration, we gathered two of the three shares at one site and reconstructed the genome analysis data.

Our next step is to expand our R&D efforts with the aim of applying the newly developed technology to other fields.

This work was performed under the “Photonics and Quantum Technology for Society 5.0” Cross-ministerial Strategic Innovation Promotion Program (SIP) of the Council for Science, Technology and Innovation (CSTI) (funding agency: National Institutes for Quantum Science and Technology (QST)).