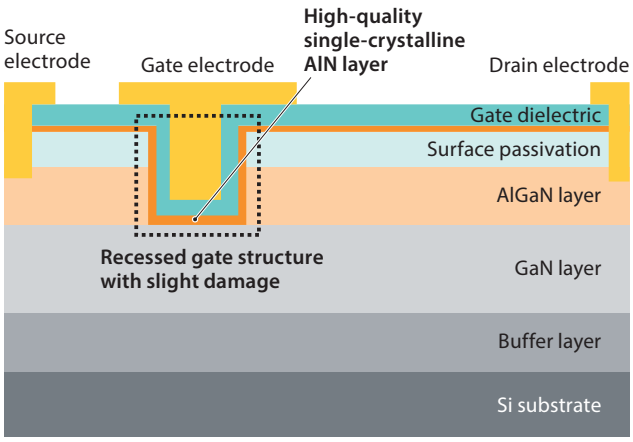
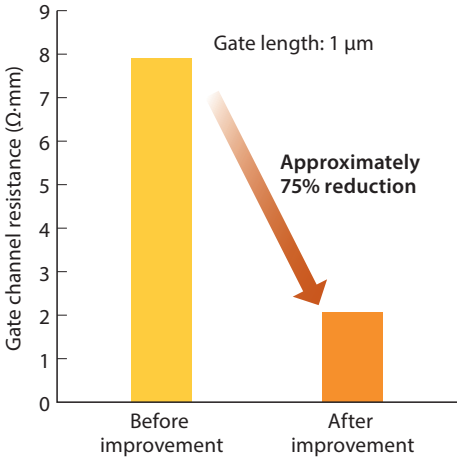
1. Research and Development

1.1 Process Technology to Reduce Gate Channel Resistance of MOS Type GaN Power Transistors



AlGaN: aluminum gallium nitride
Si: silicon

Cross-sectional structure of MOS type GaN transistor



Comparison of gate-channel resistance before and after process improvement

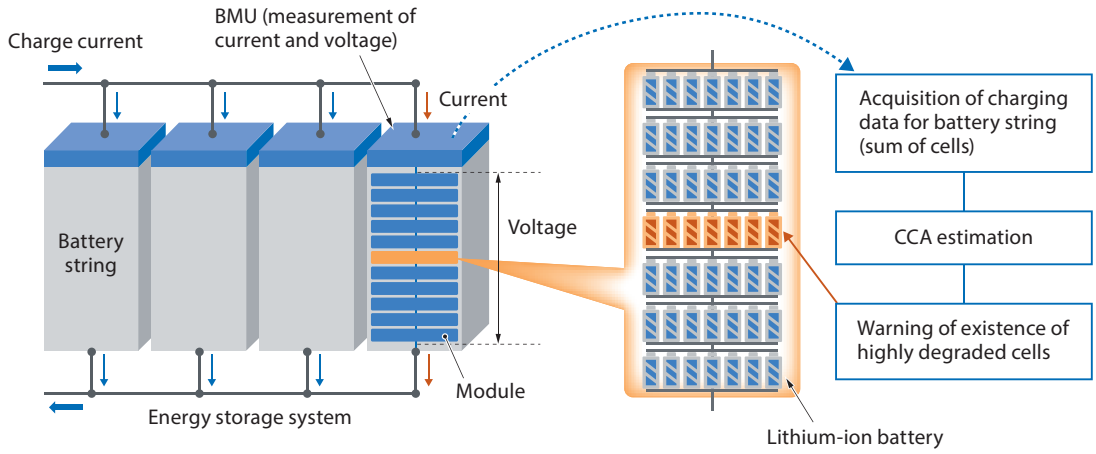
Toshiba Corporation has developed a process technology that can significantly reduce the gate channel resistance of metal-oxide-semiconductor (MOS) type gate transistors in gallium-nitride (GaN) power semiconductor devices, which make it possible to reduce the power consumption of server power supplies.

GaN-based transistors are required to achieve the normally-off operation necessary for fail-safe design. In order for a high-speed MOS type GaN power device to be normally off, a recessed gate structure is necessary. However, the conventional recessed gate structure causes an increase in the channel resistance, thereby increasing the power loss.

To solve this problem, we have developed the following two processes: (1) a process to reduce the damage to the GaN layer caused by the etching process for the formation of a recessed gate structure, and (2) a process to form a high-quality single-crystalline aluminum-nitride (AlN) layer on the recessed gate structure by means of an atomic layer deposition (ALD) method.

The newly developed process technology reduces the gate channel resistance by roughly 75% in comparison with the conventional recessed gate structure while maintaining normally-off operation. As a result, the new process technology makes it possible to realize low-loss normally-off MOS type GaN power transistors.

1.2 Estimation of Internal State of Lithium-Ion Batteries Installed in Energy Storage Systems Applying Charging Curve Analysis



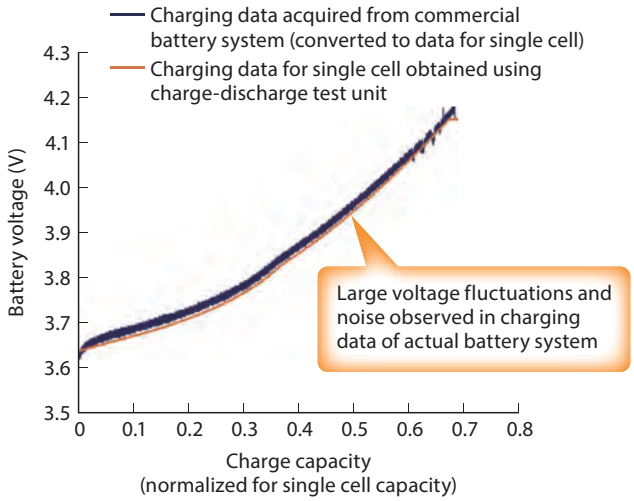
Configuration of large-scale battery energy storage system and charging curve analysis (CCA) method applying measurements per battery string

Stationary energy storage systems and electric vehicles equipped with large-capacity lithium-ion batteries have come into widespread use. However, no reliable diagnosis technology is available to estimate the safety and performance of such batteries during use.

Toshiba Corporation has been developing a charging curve analysis (CCA) technology for the diagnosis of lithium-ion batteries during use. A CCA algorithm performs regression analysis on charging data to estimate the internal state of batteries, including the cathode and anode capacities, and evaluate their safety and remaining life. It was previously difficult, however, for the CCA algorithm to obtain charging data from the thousands of cells comprising a large-scale battery energy storage system.

We have now enhanced the CCA algorithm to analyze charging data for a string unit, which can easily be acquired even from a large-scale energy storage system, and to warn of the existence of any highly degraded cells in the string. The new CCA algorithm has achieved an accuracy with an error of less than 2% for estimation of the internal state of the strings of an actual battery system, despite large fluctuations and noise in the charging data acquired from the battery management unit (BMU). This confirms that the new CCA algorithm can detect strings with highly degraded cells based on parameters indicating their internal states.

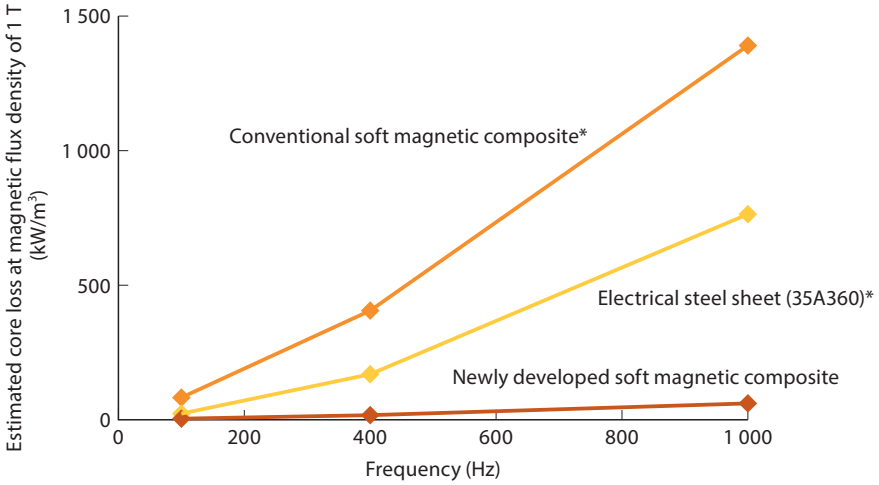
At present, we are conducting demonstration tests of the algorithm using energy storage systems composed of our SCiB™ rechargeable batteries as well as commercial battery systems manufactured by other companies.



	Results of CCA estimation		
	Battery capacity (%)	Cathode capacity (%)	Anode capacity (%)
Single cell Evaluation of data from charge-discharge test unit	100.0	100.0	100.0
Battery system Evaluation of data from actual battery system	101.4	98.9	102.2

Charging data obtained by actual battery energy storage system and results of internal state estimation using CCA method

1.3 Soft Magnetic Composite with Very Low Magnetic Loss



* Reference: Maeda, T. et al., *SEI Technical Review* 2005, 60, 3–9.

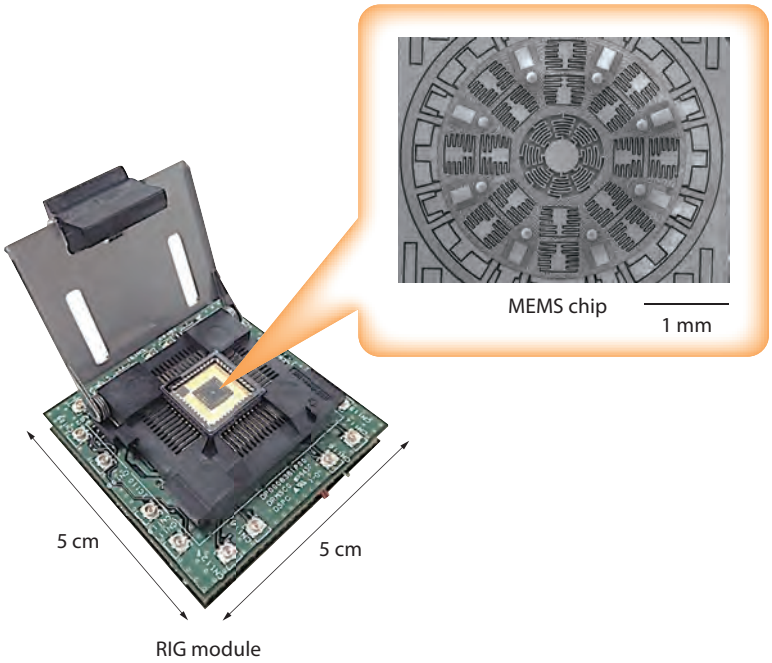
Comparison of magnetic loss (core loss) of conventional soft magnetic composite, electrical steel sheet, and newly developed soft magnetic composite at magnetic flux density of 1 T

Toshiba Corporation has developed a new soft magnetic composite that exhibits much lower magnetic loss than conventional soft magnetic composites and electrical steel sheet over a wide range of frequencies. The new soft magnetic composite helps to improve the efficiency of motor systems as well as power supply systems incorporating inductors and transformers.

Soft magnetic composites can be easily formed into complicated shapes and guide magnetic flux efficiently. They are therefore good candidates for next-generation soft magnetic materials. However, soft magnetic composites generally have large magnetic loss. It was therefore crucial to reduce their magnetic loss.

We used flattened magnetic particles because magnetic loss can be significantly reduced by controlling the magnetic properties of such particles along the flattened plane. Flattened particles of an amorphous iron-cobalt-silicon-boron (FeCoSiB) alloy were oriented in the insulating matrix and annealed under a magnetic field in the direction of the flattened plane. The annealed composite guided the magnetic flux efficiently along the direction of the magnetic field applied during the annealing process, considerably reducing the magnetic loss compared with conventional materials.

1.4 High-Precision Rate-Integrating Gyroscope



Microcontroller-based RIG module and MEMS chip

High-precision gyroscopes (gyros) are expected to be applied to a wide range of applications as a means of maintaining a reference direction, including position measurement in warehouses and factories, precision attitude control of drones, and automatic operation of robots and mobility devices.

Toshiba Corporation has developed a high-performance, rapid-response, rate-integrating gyro (RIG) module, which, unlike conventional gyroscopes, directly detects the direction in which it is pointing without integral calculation based on angular velocity. The newly developed RIG module is the world's first compact gyro module incorporating a microelectromechanical systems (MEMS) chip for direct angle detection(*) to reduce size and a microcontroller to achieve digital control. RIG operation requires an ideal resonator with a perfectly symmetrical structure for angle detection. We have resolved the asymmetry issue by leveraging our proprietary variable-resistance damper and other technologies, realizing a perfectly symmetrical resonator.

This work was partially funded by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

(*) Announced in January 2020 at the Institute of Electrical and Electronic Engineers (IEEE) MEMS 2020 Conference (as researched by Toshiba Corporation)

1.5 Mobile Palletizer Capable of Handling Multiple Conveyor Lines

Mobile palletizer capable of handling multiple conveyor lines

Palletizing work has conventionally been performed by workers manually stacking cardboard boxes on pallets or by utilizing conveyor robot arm systems. However, it is becoming difficult to secure a sufficient number of workers in Japan because of the declining labor population. In addition, the installation of robot arm palletizers is costly.

To eliminate the need for human workers for palletizing work, Toshiba Corporation has developed a mobile palletizer composed of an automated guided vehicle (AGV) and a robot arm. The AGV is designed to be able to move between multiple conveyor lines. The robot arm, which transfers cardboard boxes to pallets, can be configured for the appropriate stacking method according to the types of cardboard boxes.

We have adopted the rapid-charge SCiB™ rechargeable battery to make it possible to charge the mobile palletizer during intervals between palletizing tasks and thereby reduce the time during which conveyor lines stand idle.

Since the robot arm falls under the definition of "industrial robots" stipulated in the Ordinance on Industrial Safety and Health of Japan, safety fences or equivalent safety systems are required around the mobile palletizer. Therefore, a safety monitoring area is allocated for each pallet to control the mobile palletizer so that it does not come close to human workers. This makes it possible to ensure the safety of workers without reducing the palletizing efficiency.

1.6 Laser Welding and He Sealing Production Line for He-Sealed Nearline HDDs

Laser welding and He sealing production line
for He-filled nearline HDDs

Toshiba Electronic Devices & Storage Corporation has released helium (He)-sealed nearline hard disk drives (HDDs) with the industry's highest capacity of 16 Tbytes(∗1)(∗2), which are suitable for use in storage server systems.

To seal He gas in the HDD enclosure, the Corporate Manufacturing Engineering Center of Toshiba Corporation developed a laser welding technology and an automatic welding machine for HDD production lines. The laser welding technologies extensively cultivated by the Toshiba Group for the manufacturing of various products were fully utilized for this purpose. For example, the HDD enclosure is made of aluminum die-cast parts in which tiny voids are inevitably formed. We adjusted the laser welding parameters to eliminate through-holes at the welding marks, thereby achieving high-quality sealing.

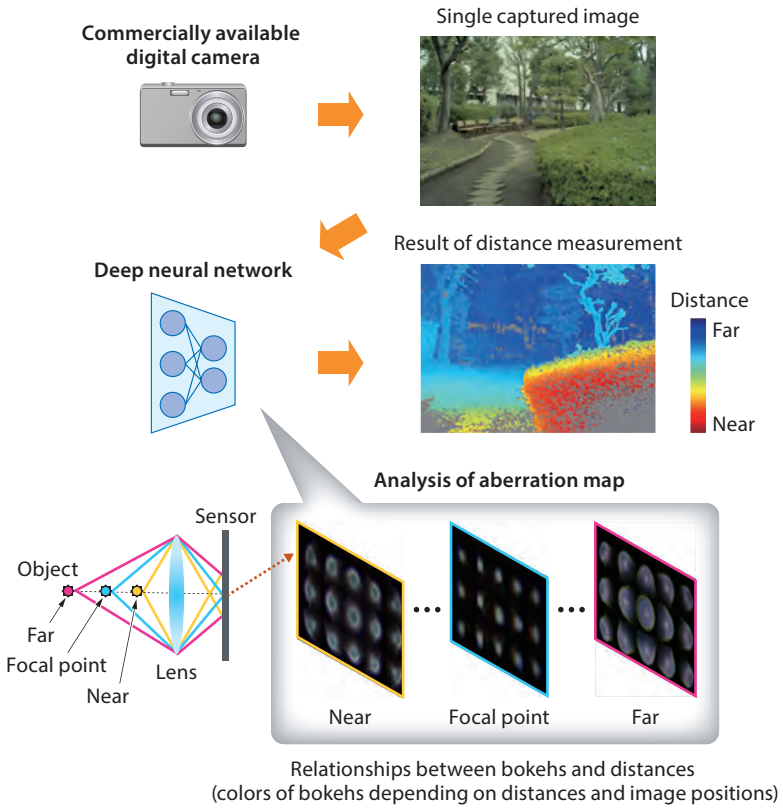
The newly developed laser welding machine features a high-speed, low-shock HDD transfer system, a high-speed, high-accuracy positioning mechanism, and an inline welding quality inspection system, which make it possible to maintain high quality and productivity.

We will increase the number of automatic HDD production lines to ensure a stable supply of He-sealed nearline HDDs.

(∗1) Definition of capacity: Toshiba Electronic Devices & Storage Corporation defines a terabyte (Tbyte) as 10^{12} (1 000 000 000 000) bytes.

(∗2) As of January 2019 for 3.5-inch conventional magnetic recording (CMR) HDDs with a height of 26.1 mm (as researched by Toshiba Electronic Devices & Storage Corporation)

1.7 Distance Measurement Technology Using Monocular Camera Based on Aberration Maps



Overview of distance measurement based on aberration maps of image captured by monocular camera

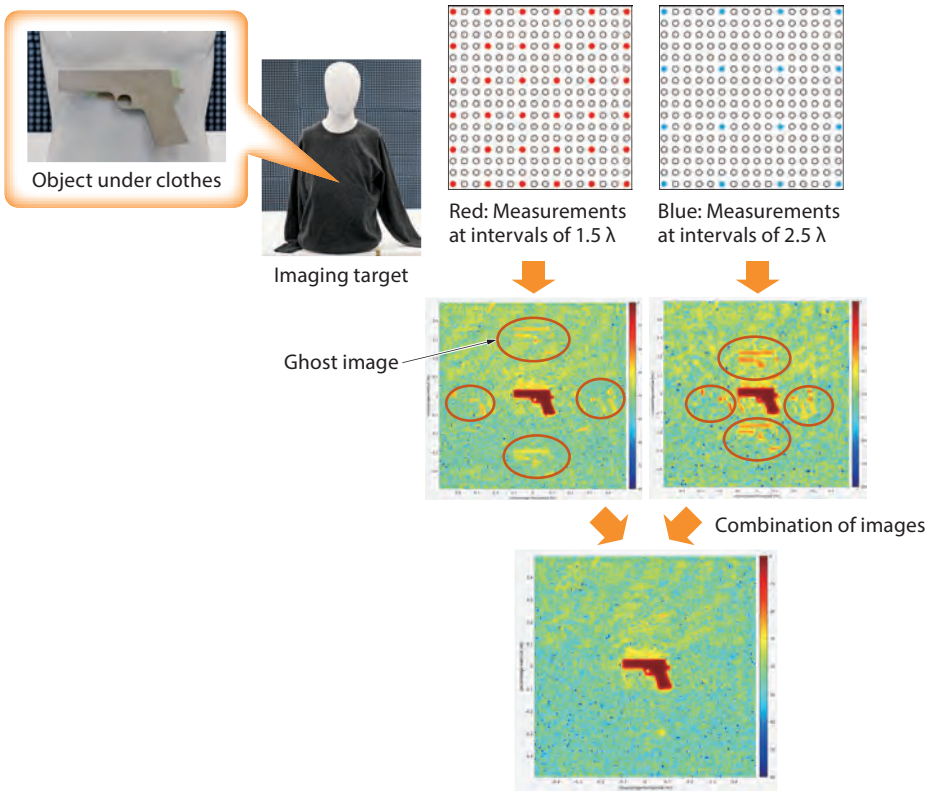
Toshiba Corporation has developed a technology to produce a depth image from a single image captured with a commercially available digital camera.

Stereo cameras are widely used as a means of achieving image-based distance measurement with high accuracy. It is difficult, however, to reduce the size of stereo camera systems incorporating two cameras. It has also been considered impossible to measure distances using a monocular camera without special color filtering or other additional processing.

Overturning these preconceived ideas, the newly developed technology measures the distances to different parts of an object by analyzing aberration maps of bokehs (blurs) based on the relationships between lens aberrations (bokehs) and distances. The newly developed technology uses a deep neural network to learn these relationships because it is too complicated to model them mathematically. As a result, a single digital camera can now provide accurate depth features comparable to those attained by a stereo camera regardless of the shape of the target object.

The new technology has a wide range of applications such as enhancement of the functionality of cameras, automation of maintenance services, and high-precision product inspection.

1.8 Millimeter-Wave Radar Imaging Technology for Security Support Systems



Example of image of concealed object created by millimeter-wave radar imaging technology

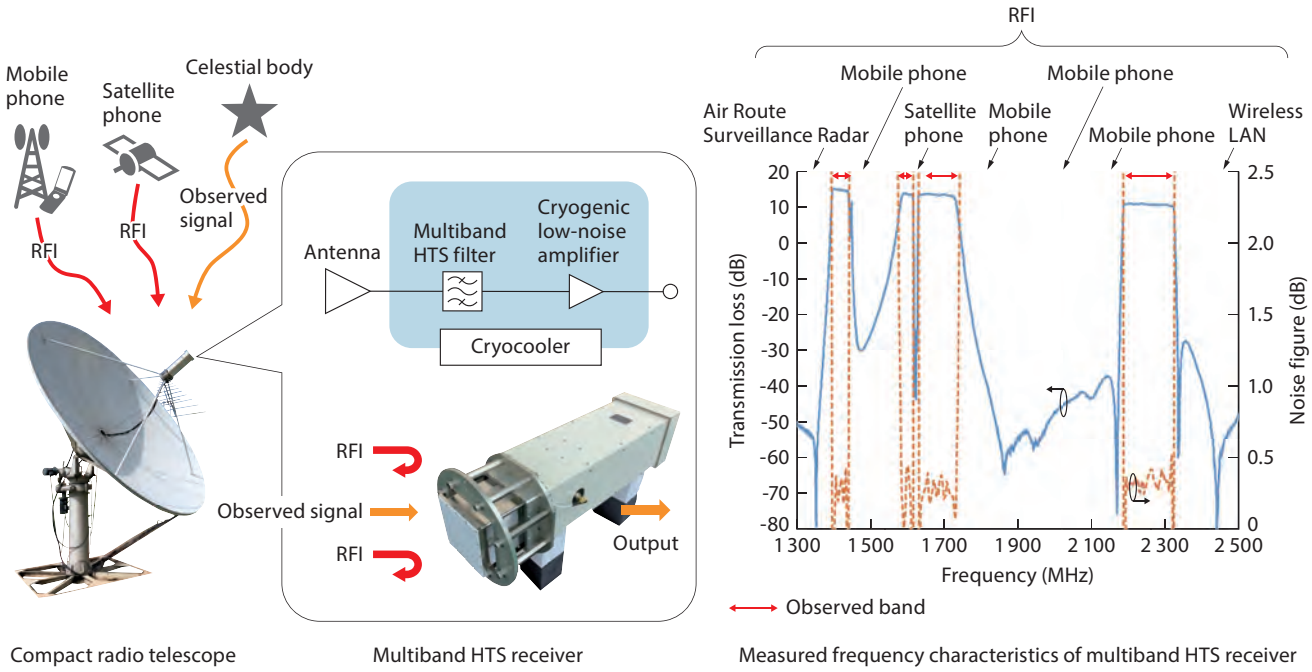
If a suspicious person is carrying a weapon such as a knife or an explosive device concealed under their clothes, it is almost impossible to detect it with surveillance cameras. It is inconvenient, however, to interrupt the flow of people in public places such as railway station ticket gates and facility entrances in order to perform security checks.

Conventional radar imaging technology requires a certain amount of time to generate high-definition images because measurements are necessary using antennas arranged at intervals of half the radar's wavelength. Measurements using antennas arranged at intervals of more than half the radar's wavelength produce undesirable ghosting.

To solve these problems, Toshiba Corporation has developed a new technology that combines two images obtained by measurements using millimeter-wave radar at mutually prime intervals in order to cancel out each other's ghosting. The newly developed technology can generate high-definition images with roughly one-seventh the number of measurements required at half-wavelength intervals.

This will make possible the screening of suspicious persons in public places without interrupting the flow of people, facilitating security checks.

1.9 Compact Multiband High-Temperature Superconducting Receiver for Radio Telescopes Capable of Reducing Radio-Frequency Interference



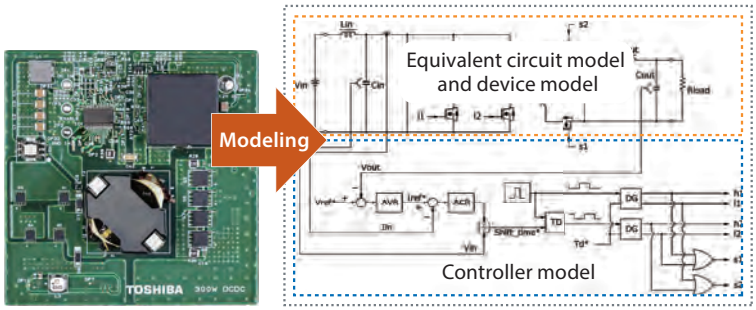
Configuration and frequency characteristics of multiband HTS receiver

The objective of radio astronomy is to elucidate astronomical phenomena through the utilization of radio telescopes that can detect very weak radio-wave signals of various frequency bands emitted by celestial bodies. However, as frequency resources become depleted owing to the recent rapid increase in the number of smartphones and other wireless communication devices, it has become necessary to share the available frequency bands with these wireless devices.

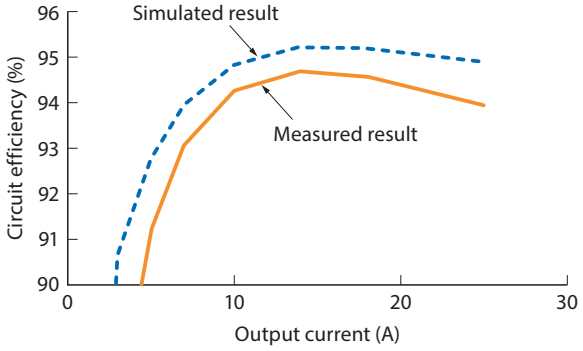
In response to this situation, Toshiba Corporation has developed a compact multiband high-temperature superconducting (HTS) receiver for small to large radio telescopes. Capable of observing multiple frequency bands simultaneously, this HTS receiver uses a low-loss multiband HTS filter and a cryogenic low-noise amplifier cooled to the temperature of liquid nitrogen (−196°C) to suppress radio-frequency interference (RFI) caused by other wireless devices. Experiments with a prototype quad-band HTS receiver have shown high sensitivity, with a reduction in RFI of more than 40 dB and a noise figure of less than 0.4 dB.

We will apply this technology to wireless infrastructure systems in addition to radio telescopes.

1.10 Accurate Circuit Power Loss Simulation for Efficient Development of Power Devices



Simulation environment to evaluate power loss of circuit board with power devices installed



Comparison of measured and simulated circuit efficiency

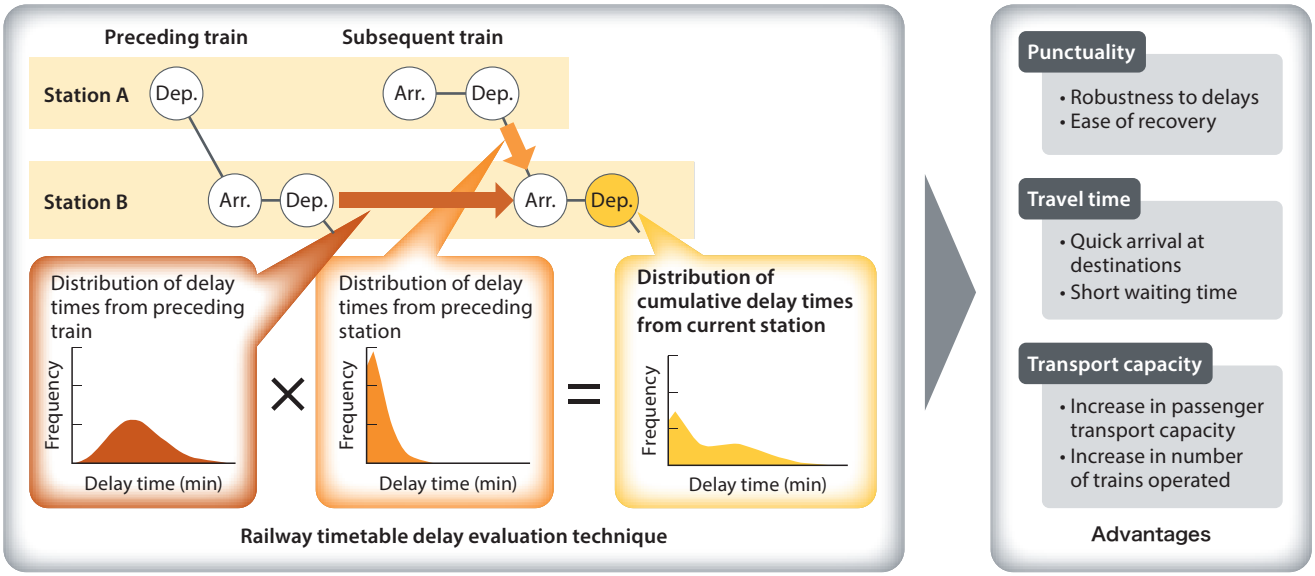
Toshiba Corporation is developing power devices that provide the optimal performance when mounted on customers' circuit boards. To reduce development iterations and improve the performance of power devices, we have developed a circuit simulation environment that makes it possible to accurately analyze power loss by modeling a circuit with power devices.

The newly developed simulation environment consists of an electric circuit model and a controller model. The electric circuit model is composed of an equivalent circuit model that can accurately estimate power loss and an accurate power device model. The controller model, which is derived from a numerical calculator, can apply appropriate output voltage to an arbitrary load.

This simulation environment allows observation of the voltage and current at any point in the circuit, in order to analyze power loss in detail. Furthermore, it is also possible to evaluate voltage and current conditions that are unmeasurable in a real circuit board.

The use of the new simulation environment is expected to help reduce the number of prototyping cycles, facilitating the release of low-loss power devices. Our next step is to expand the types of circuit models to satisfy various customer needs.

1.11 Railway Timetable Evaluation Technique



Dep.: departure Arr.: arrival

Advantages of evaluation of secondary delay time from train schedule

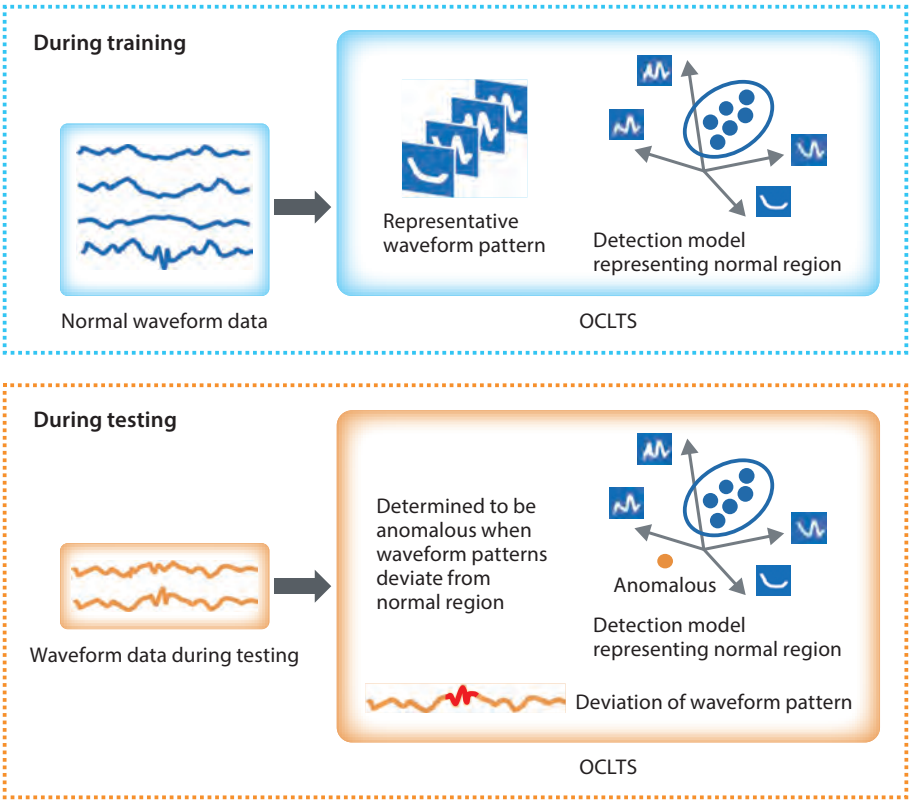
In recent years, train delays, particularly consecutive secondary delays of subsequent trains, have become a social issue because significant secondary delays severely disrupt the train schedule, no matter how rarely such a disruption occurs. It is therefore important for railway operators to accurately assess and predict the risk involved in order to ensure on-time train operations. However, the conventional method relies on repetitive simulations based on the hypotheses of multiple delay scenarios and consequently requires a huge amount of computer run-time to accurately evaluate significant secondary delay events.

To resolve this issue, the Toshiba Group has developed a railway timetable evaluation technique to create railway timetables that are robust to secondary delays. This technique makes it possible to accurately calculate the distribution of secondary delays of all trains using a probability propagation model and to have the model learn the actual results of train operations. Furthermore, since the newly developed technique directly handles secondary delay distribution data, it eliminates a large number of simulations.

A performance evaluation based on actual timetable data has shown that the new technique can calculate the distribution of secondary delays of all trains at all stations within one second. Therefore, the new technique can create even large-scale robust railway timetables, contributing to the improvement of customer convenience and satisfaction as well as the management efficiency of railway operators.

In September 2019, we concluded an agreement with Greater Anglia, a train operating company in the United Kingdom, on a railway timetable creation project in partnership with Mitsui & Co., Ltd.

1.12 OCLTS: Interpretable AI Technology to Detect Anomalies Using Only Normal Waveforms

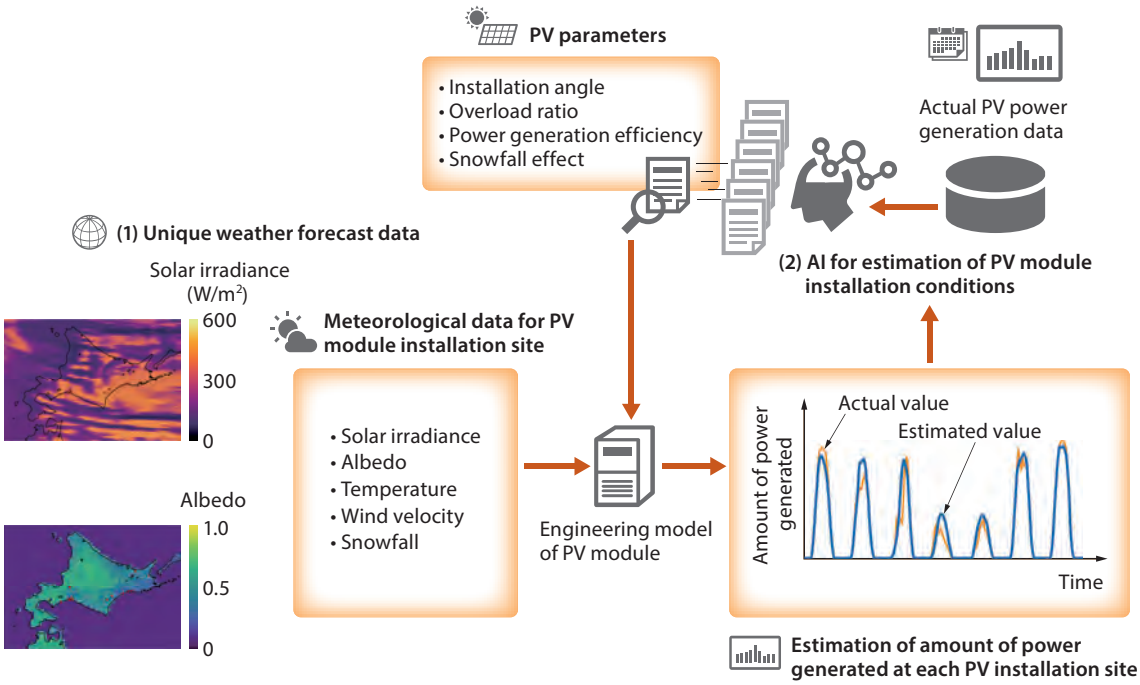


Outline of anomaly detection method using OCLTS

In order to monitor the conditions of infrastructure facilities and manufacturing equipment, industry has been establishing environments to collect waveform data using various sensors. However, because anomalies are rare, it is still difficult to collect anomaly data with which to train artificial intelligence (AI) models. In addition, in the event of an anomaly being detected, expert engineers often investigate its causes using waveform data and devise countermeasures accordingly.

In this context, Toshiba Corporation has developed one-class learning time-series shapelets (OCLTS), an AI-based anomaly detection technology with high interpretability that learns both representative waveform patterns (shapelets) and an anomaly detection model without anomaly data. It is difficult to apply conventional technology to infrastructure facilities and manufacturing equipment because of the need to learn shapelets using anomaly data. In contrast, OCLTS identifies deviations from normal waveform patterns to support expert engineers in investigating the causes of an anomaly and devising countermeasures. We have confirmed that the anomaly detection performance of OCLTS is superior to that of the conventional technology.

1.13 Highly Accurate Photovoltaic Power Generation Forecasting Technology Using Artificial Intelligence



Outline of highly accurate PV power generation forecasting technology using AI

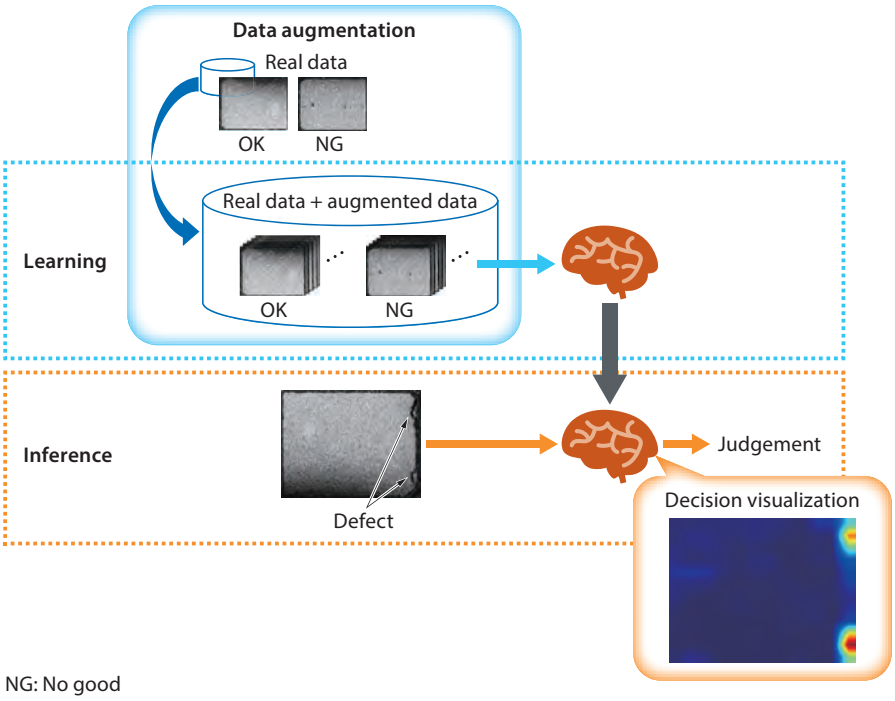
The amount of power generated by photovoltaic (PV) panels depends on the weather conditions. As the installed capacity of renewable energy increases, precise forecasting of PV power generation becomes indispensable for electricity supply-and-demand management.

Conventional PV power generation forecasting uses engineering models based on the equipment conditions (PV module capacity, azimuth, tilt angle, etc.) and weather forecast data for the PV module installation site such as solar irradiance and temperature.

Toshiba Corporation has now developed a highly accurate PV power generation forecasting technology with the following features: (1) the use of additional weather forecast data such as wind velocity, snowfall, and albedo (reflectance of the ground surface) obtained from numerical weather simulation, and (2) the use of AI software for estimation of the PV module installation conditions, which learns the actual amounts of power generated in order to optimize the PV parameters incorporated into the engineering model.

We have confirmed that the newly developed technology reduces the forecast error by 9.8% compared with the conventional forecasting method. We will apply this technology to electricity management systems and virtual power plant services.

1.14 Automatic Visual Inspection Using Deep Learning



Data augmentation and visualization for visual inspection using deep learning

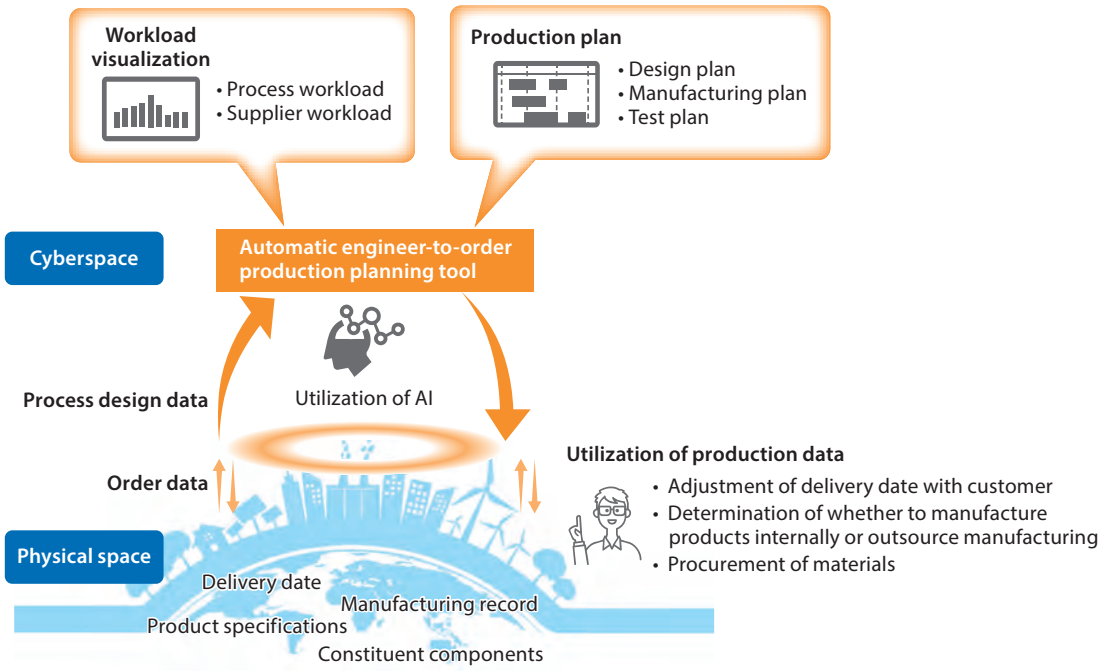
As a means of alleviating rising labor costs and solving the issue of variations in workers' manual inspection skills, there is growing demand for the automation of visual inspection processes at factories. Deep learning is an effective tool for image recognition and classification. However, a large amount of labeled data, particularly defect data, is required for the successful application of deep learning because insufficient data will result in reduced accuracy as a result of over-fitting. It is also necessary to provide an explanation of the inspection results, which is usually a "black box" in machine learning.

Toshiba Corporation has developed a data augmentation and defect position visualization technology to resolve these issues. In deep learning, data augmentation is typically performed by slightly and randomly zooming, rotating, and adding noise to real images. For further data augmentation, we have employed computer graphics composition and other image processing techniques, randomly changing various parameters and thereby creating tens of thousands of synthetic images for learning.

For example, we have combined images of defects created using computer graphics and extracted from real images with images having no defect. In addition, we have visualized defect positions by removing the background and non-defective areas from the feature maps in a middle layer of the deep-learning model, thereby highlighting defects much smaller than the size detectable with existing visualization methods.

These technologies are highly versatile and will be introduced to various manufacturing sites in the near future.

1.15 Automatic Production Planning Tool for Engineer-to-Order Products



Overview of automatic engineer-to-order production planning tool

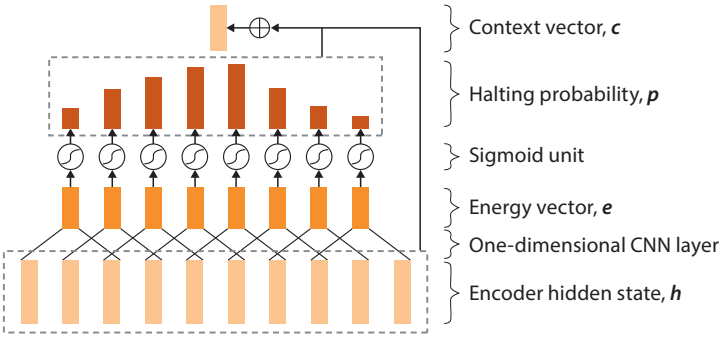
Toshiba Corporation has developed a tool that significantly reduces the time required for the planning of engineer-to-order production.

Since each engineer-to-order product has different specifications, its design is created after an order is received. Furthermore, all production processes must be planned, including arrangement of the delivery date, determination of whether to manufacture the product internally or outsource some or all of the manufacturing processes, and parts procurement. The conventional planning approach has relied on engineers' individual expertise to achieve these tasks.

We adopted an approach in which the order data received by the sales department and the process design data derived from the product specifications are placed under unified management so that the newly developed production planning tool can create schedules for the design, manufacturing, and testing processes. This tool makes it possible to visualize the workload of all manufacturing processes and suppliers, reducing the time required for coordination among the related departments as well as the planning time.

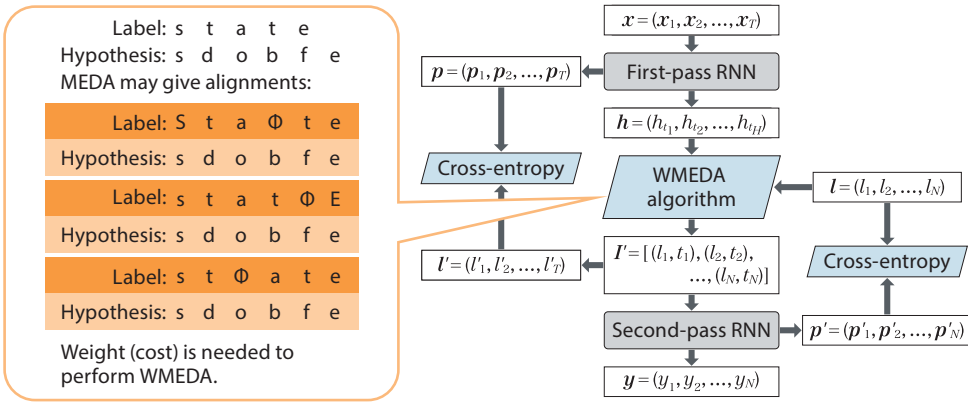
Our next step is to enhance the efficiency and accuracy of planning by utilizing AI based on design and actual manufacturing data.

1.16 Technique to Improve Performance of Automatic Speech Recognition Utilizing End-to-End Model



CNN: convolutional neural network

Adaptive computation steps (ACS) algorithm for improvement of speech recognition accuracy



MEDA: minimum edit-distance alignment
RNN: recurrent neural network

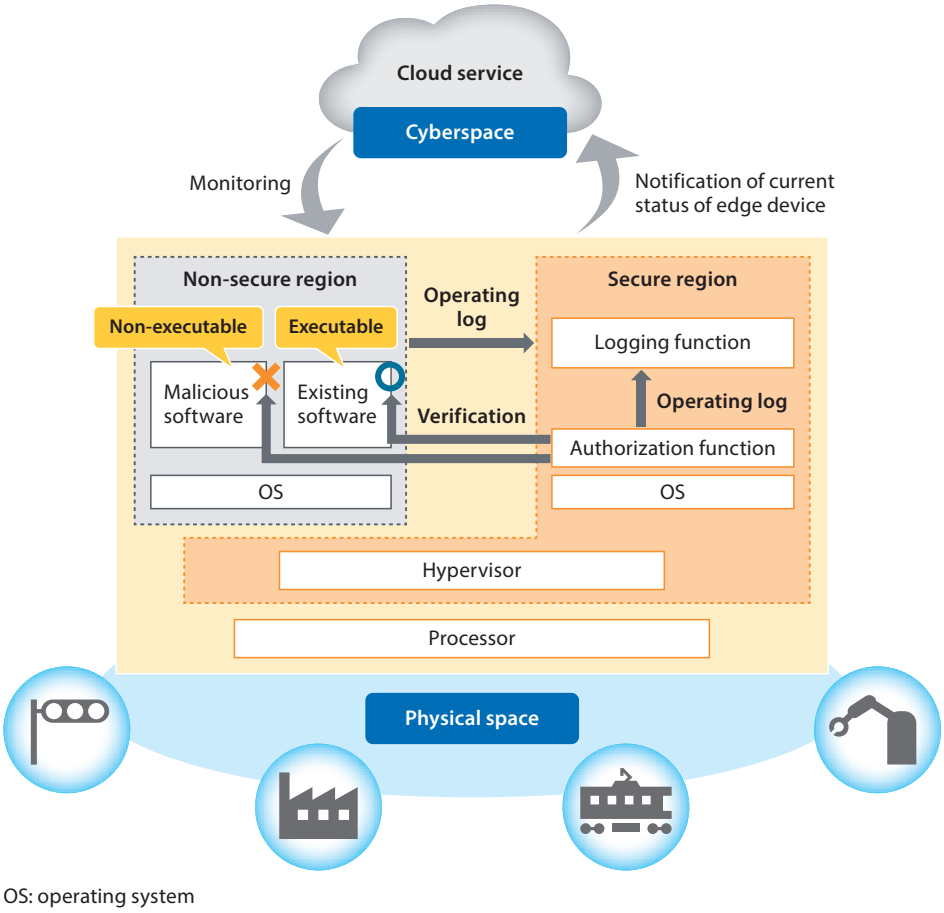
Training flow using newly developed technique

Weighted minimum edit-distance aligning (WMEDA) algorithm for shortening of training time

Studies on automatic end-to-end speech recognition in which pairs of input and output data are learned in a single model have been performed throughout the world. However, many issues remain to be solved, including recognition accuracy and processing time.

Toshiba (China) Co., Ltd. has developed unique algorithms to overcome these issues. In order to improve recognition accuracy, we have devised an adaptive computation steps (ACS) algorithm that dynamically decides the number of calculation steps executed in the speech recognition model. This algorithm has been shown to reduce the character error rate (CER) from 32.4% to 31.2% in the case of online character recognition and from 22.0% to 18.7% in the case of offline character recognition. In addition, we have applied the weighted minimum edit-distance aligning (WMEDA) algorithm to the training process of the speech recognition model, reducing the training time by 45.7% compared with the conventional method and the CER from 19.43% to 19.38%.

1.17 Secure Logging Technology for Embedded Devices



OS: operating system

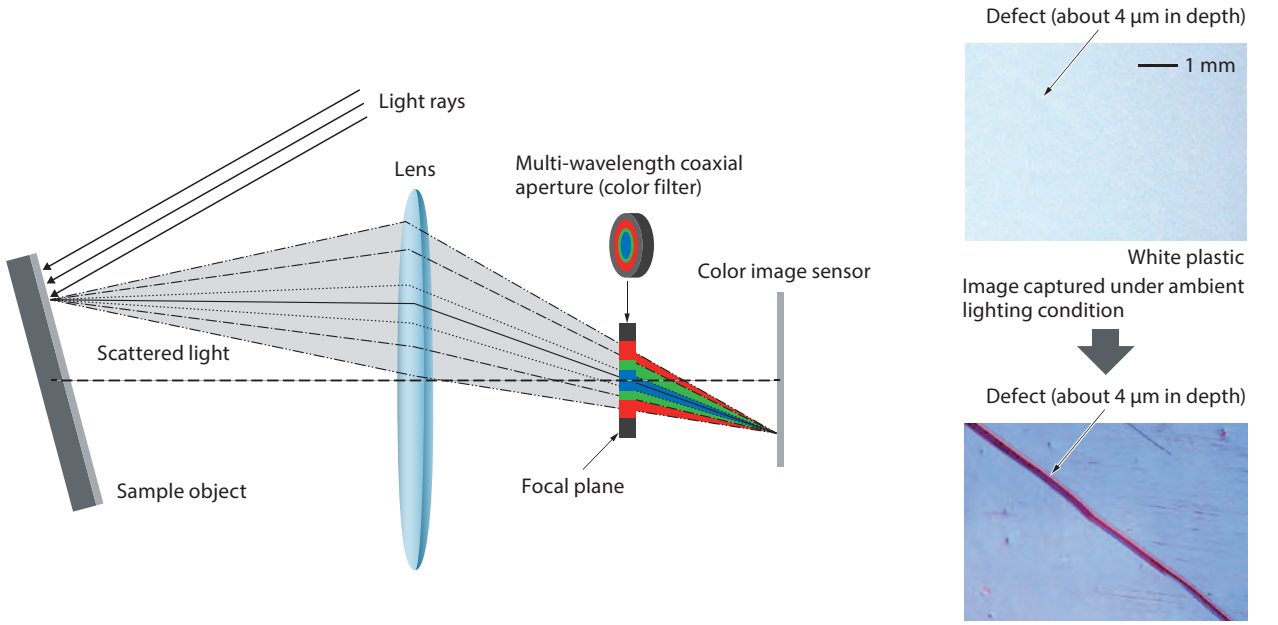
Logging technology to prevent tampering with log data in edge devices of CPS

The operating conditions of factories and social infrastructure facilities such as water treatment plants are remotely monitored using cloud-based technology in order to detect abnormal behavior and signs of failures. Such monitoring is performed based on system operating logs. However, in the event of operating logs being altered or deleted by a cyberattack, it becomes impossible to grasp the system conditions via the cloud. Such a situation could lead to a severe accident in the worst-case scenario.

To prevent this problem from occurring, Toshiba Corporation has developed a secure logging system that partitions the operating region of a system into a secure, access-restricted region and a non-secure region using virtualization technology. The logging process runs in the secure region to prevent tampering with logs. We have also developed an authorization function to detect tampering with binary software executables.

Our next step is to develop a resilience function capable of restoring edge devices from abnormal conditions. We will incorporate these functions into platforms essential for the realization of cyber-physical systems (CPS).

1.18 Nondestructive Optical Inspection Technology for Detection of Microdefects



* Based on Ohno, H. and Kano, H. *Optics Express* 2018, 26, 20:25880–25891.

Image captured using our technology

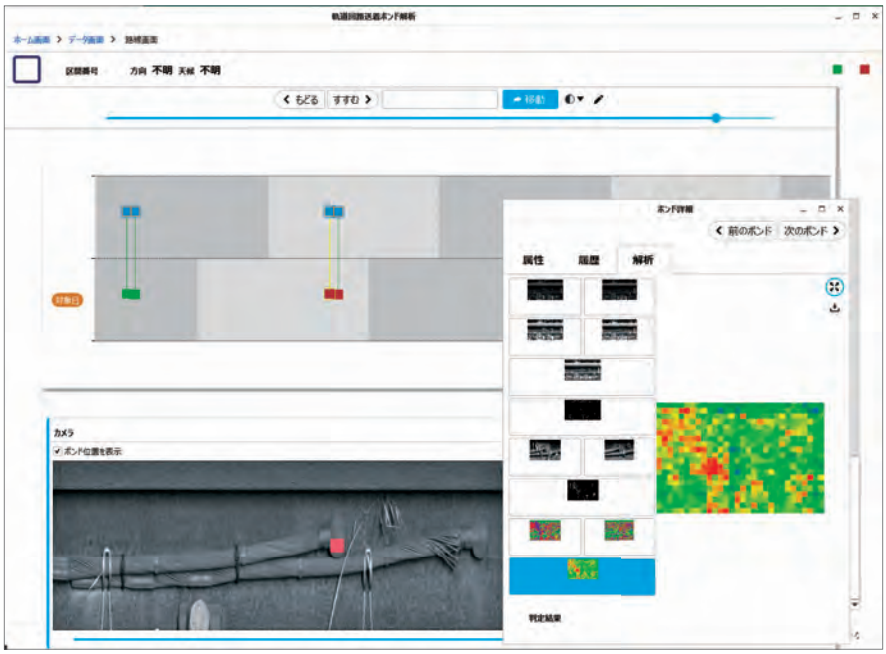
Example of image of shallow defect of about 4 μm in depth captured by nondestructive optical inspection technology

In recent years, the manufacturing industry has been accelerating the development of inspection technologies using optical imaging systems. Coupled with IoT (Internet of Things) solutions, AI-based analysis of images captured by an optical imaging system is expected to improve the efficiency of industrial manufacturing processes. However, skilled personnel are still necessary to perform visual or tactile inspections from various angles of view in order to detect microdefects on product surfaces such as small scratches, dust particles, and foreign substances.

The light reflected by microdefects is slightly scattered and deflected compared with the light reflected by a smooth surface. It is therefore possible to identify microdefects by monitoring the deflection of slightly scattered light.

To monitor such deflection, Toshiba Corporation has developed an optical system incorporating a collimated light source to illuminate product surfaces, an imaging lens, and a concentric color filter (concentrically arranged multi-wavelength filter assembly) placed on the focal plane of the imaging lens to separate light rays into different wavelengths according to the magnitude of the light deflection angle. The newly developed optical system enables one-shot imaging of microdefects, highlighting them in a color different from their surroundings. This optical system is designed based on light scattering analysis using Hamiltonian optics. We have confirmed the capability of this nondestructive optical inspection technology to accurately identify microdefects.

1.19 Anomaly Detection Technology for Railway Track Circuit Inspection



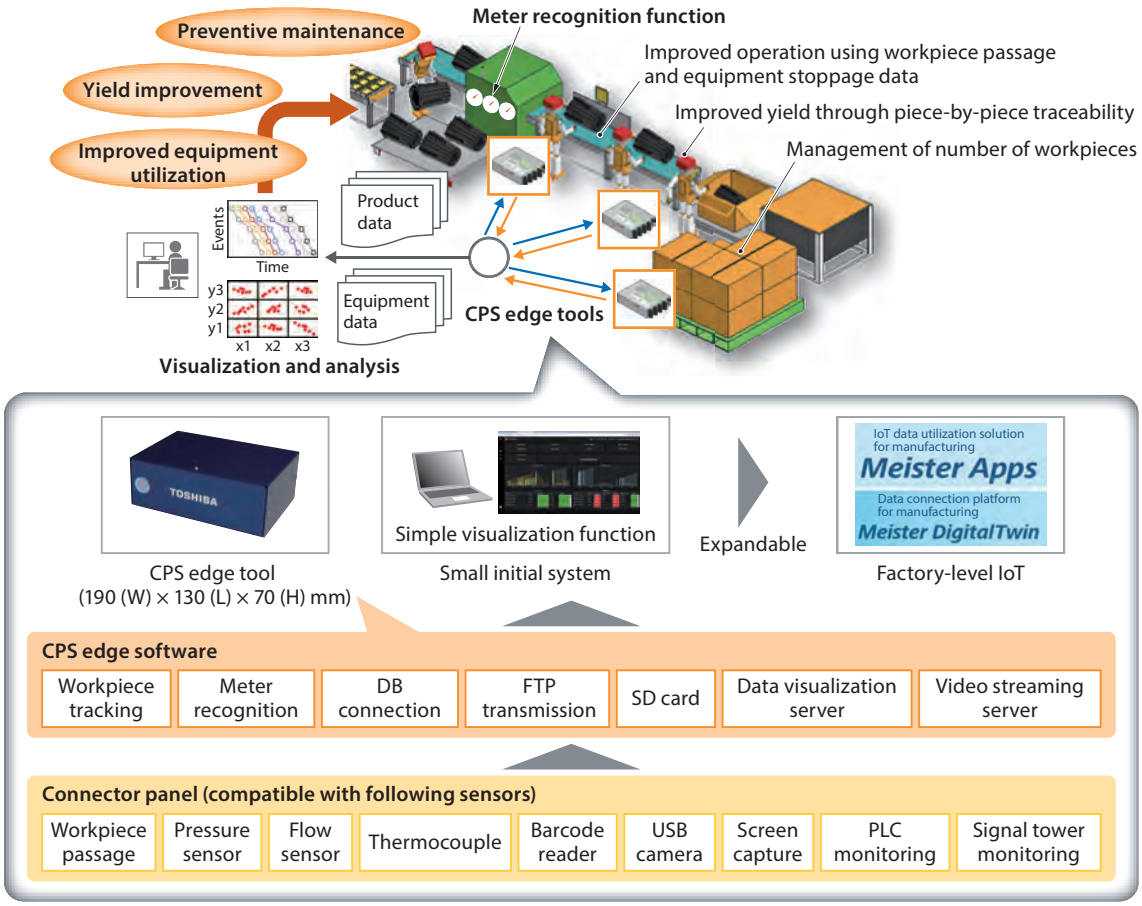
Example of operation display of anomaly detection system to identify failed part of track circuit components

Railway systems have electrical devices called track circuits to detect the presence or absence of a train on a section of the rail track. If any component of a track circuit is damaged, disconnected, or lost, the safety and stability of railway operations will be affected. Therefore, railway operators regularly perform visual inspection of the large number of components comprising their track circuits.

To contribute to improvement of the efficiency of maintenance work, Toshiba Corporation has developed an algorithm that automatically detects anomalous components using images of the sides of rails captured by track material monitoring devices installed on commercial trains. This algorithm detects anomalies by (1) automatically detecting component positions using unique co-occurrence histograms of oriented gradients (CoHOGs); (2) precisely aligning the positions and directions of cameras, which vary on each shooting day; and (3) comparing the image of a given target on the inspection day with the corresponding image of a reference day.

We have confirmed that the newly developed algorithm can detect anomalous components found by visual inspection at a practical level. We will deliver anomaly detection systems incorporating this algorithm to maintenance and inspection sites.

1.20 CPS Edge Tool to Connect Existing Equipment to IoT Networks



DB: database FTP: File Transfer Protocol USB: Universal Serial Bus PLC: programmable logic controller

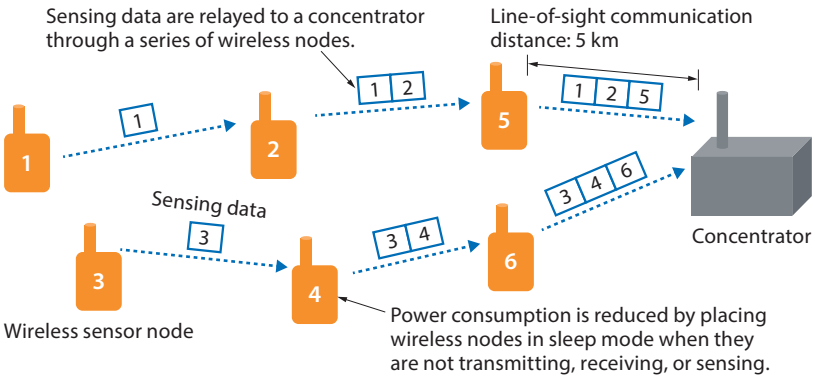
Overview of CPS edge tool to connect existing equipment to IoT networks

Factories need to collect data from existing robots and legacy automation equipment via a network in order to build an optimal cyber-physical system (CPS).

Toshiba Corporation has developed a CPS edge tool that allows a variety of equipment to be easily retrofitted with sensors to collect data. This CPS edge tool is equipped with sensors, a connector panel for network connection, and a simple visualization function. A workpiece tracking function, which associates production information with the collected sensor data, enhances analysis capabilities, thereby improving product quality and factory availability. The CPS edge tool is also equipped with a function to capture images of equipment meters without a digital output function and convert the captured images into digital data. Meters can be read stably even when their position, size, and tilt change within the camera's field of view.

We will deploy the CPS edge tool in our factories to improve production efficiency and promote its use for preventive maintenance.

1.21 Technologies for Maintenance-Free Wide-Area Wireless Multihop Network with Low Power Consumption



Operation of multihop communication with low power consumption to achieve longer range and larger capacity transmission

Toshiba Corporation has already developed a wireless multihop network system(*) offering low power consumption with a line-of-sight communication distance of 1 km and a data delivery rate of more than 99.999%. We have now developed technologies that further enhance the system by providing the following features:

(1) A proprietary wireless module is utilized to improve reception sensitivity, increasing the communication distance from 1 km to 5 km.

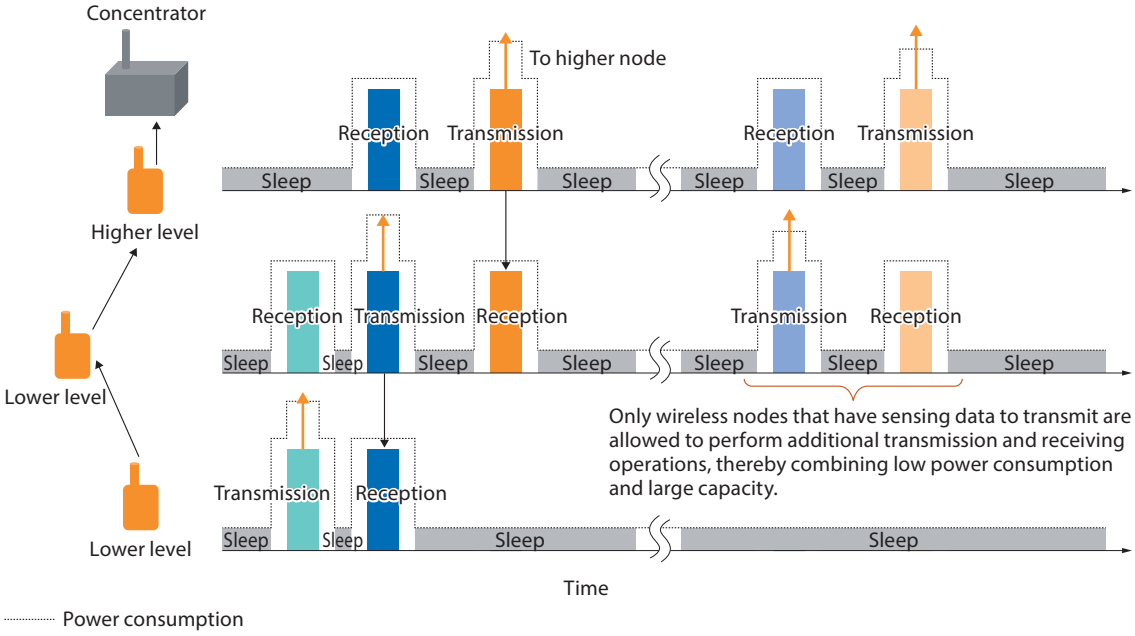
(2) Multiple data are combined together for transmission using the minimum necessary number of communications, thereby increasing the communication capacity without compromising low power consumption.

(3) The proprietary wireless module reduces variations in transmission delay and improves synchronization accuracy, decreasing the occurrence of communication failures due to synchronization deviation.

These technologies help to increase the transmission distance, capacity, and reliability of wireless multihop communications, realizing a wireless system that can accommodate various requirements.

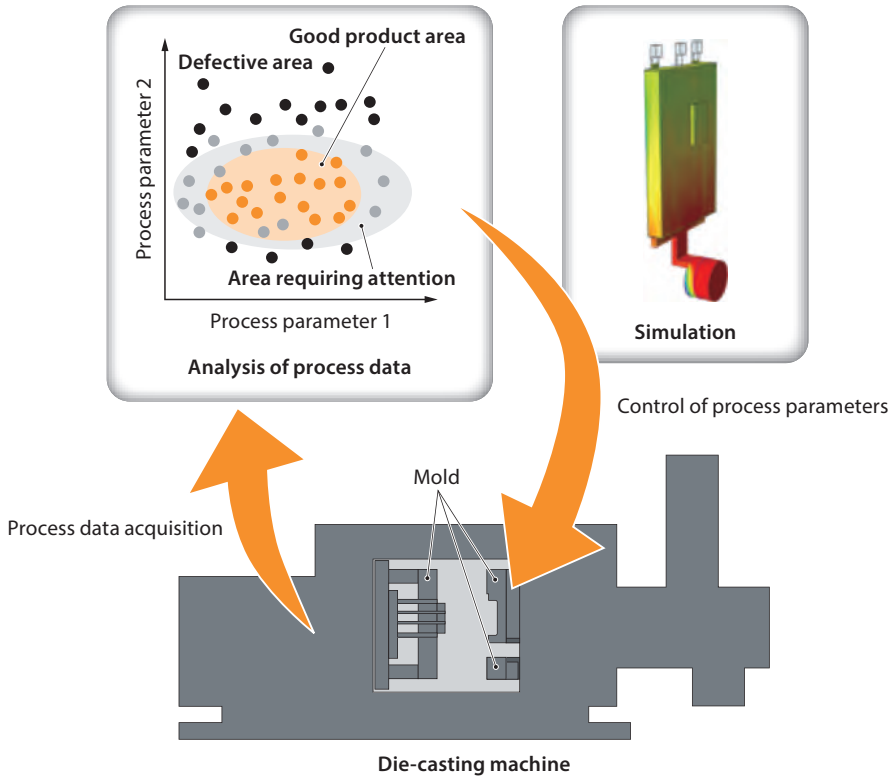
These newly developed technologies were incorporated into an IoT wireless system released in May 2019, and have also been applied to a wireless vibration sensing system to enhance the function of automatic elevator recovery in the event of an earthquake.

(*) A communication technology that successively relays received data from one node to another



Operation of time-division communication with low power consumption to reduce occurrence of transmission failure

1.22 Manufacturing IoT Technology to Support Improvement of Quality and Productivity of Die Casting



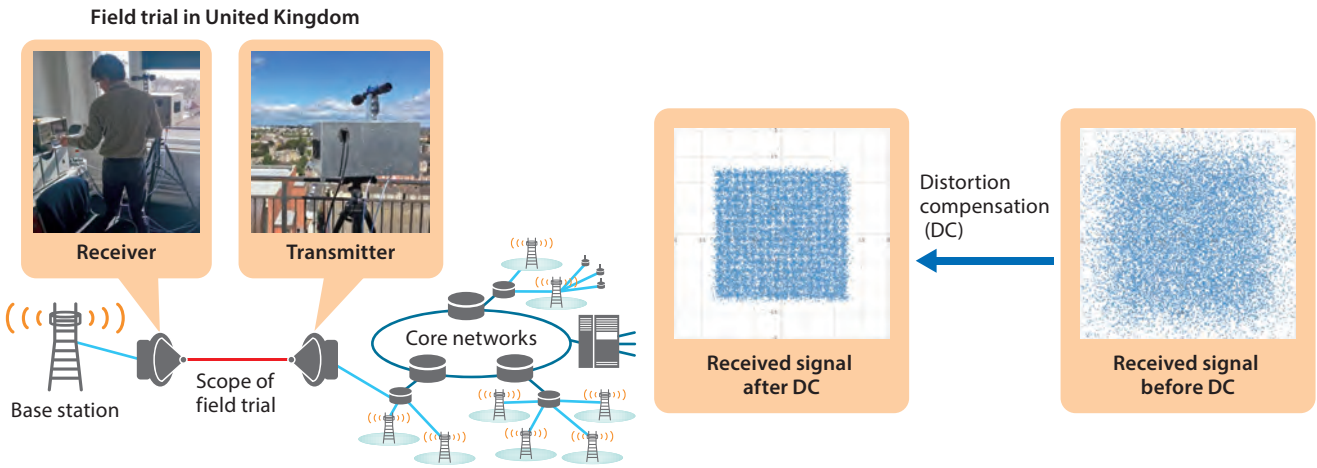
Overview of application of manufacturing IoT to die-casting process

Toshiba Corporation has developed manufacturing IoT technology to analyze relationships with past process data in the event of quality defects occurring in the die-casting process.

Die casting, a manufacturing method in which molten metal is injected into a mold cavity and solidified, is suitable for the mass production of high-precision parts. Nowadays, it is common to control the production of die-cast parts by monitoring process data such as process parameters and operating conditions (quality, etc.).To reduce manufacturing waste and improve yield, it is important to analyze and utilize process data at an early stage. However, a long time is required even for experienced engineers to classify defects, analyze their causes, and devise countermeasures.

The newly developed technology facilitates the implementation of countermeasures for manufacturing defects. We have performed a verification test at a manufacturing site and confirmed the effectiveness of quality control using process data. In the future, we will utilize the acquired process data for simulations to develop an automatic process control technology that will make it possible to produce good products while predicting phenomena and deriving optimal process parameters.

1.23 High-Speed Backhaul Technology for Cellular 5G Networks



Example of data measured in field experiments on prototype wireless transmission system applying high-speed backhaul technology

The fifth-generation (5G) mobile network is attracting considerable attention as an enabler of various types of wireless services. To achieve wide 5G coverage, it is necessary to be able to install base stations anywhere easily and quickly. The most promising approach to 5G network deployment is high-speed peer-to-peer wireless backhaul with a data rate exceeding 10 Gbits/s.

Toshiba Corporation has developed a prototype wireless transmission system that provides a data rate of 20 Gbits/s in the 70 GHz millimeter-wave band. This system is based on dual polarized multi-input, multi-output (MIMO) using an orthogonal frequency division multiplexing (OFDM) scheme, which operates reliably in various radio propagation environments. We have succeeded in a field trial of wireless transmission over a distance of 0.9 km, which was designed to emulate a transmission of 5 km(*1).

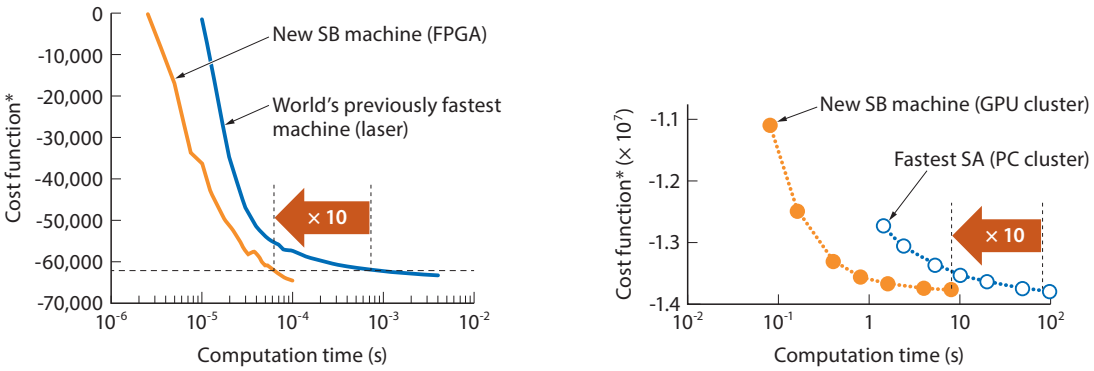
The newly developed wireless transmission system has various advanced features, including a high-directivity antenna, unique frame formats, compensation algorithms to mitigate polarization leakage, and radio-frequency (RF) circuit impairments for broadband signals. As a result, it achieves the stable signal-to-noise ratio necessary to demodulate 256-QAM(*2) signals.

This system makes it possible to provide support for quick and low-cost installation of 5G backhaul networks even in areas where it is difficult to lay optical fibers such as densely populated cities, rural areas, and mountainous locations.

(*1) Propagation attenuation was emulated by inserting a physical attenuator on the receiver side.

(*2) QAM: quadrature amplitude modulation

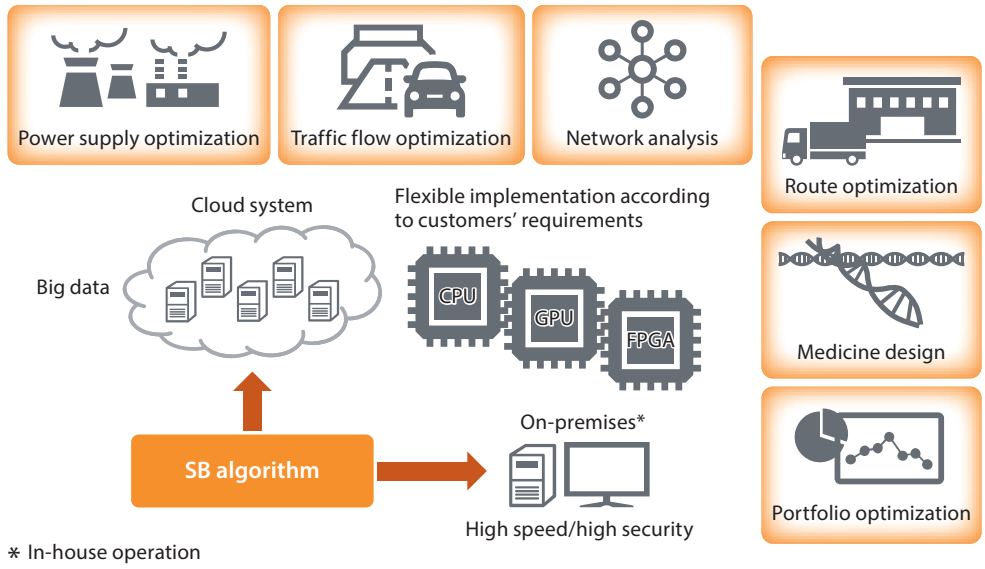
1.24 Simulated Bifurcation Machine Realizing World's Fastest and Largest-Scale Combinatorial Optimization



Results of 2 000-bit problem **Results of 100 000-bit problem**

∗ Lower values mean cost function closer to solution.

Comparison of performance of conventional techniques and simulated bifurcation (SB) machine



∗ In-house operation

Examples of application of SB machine to various social and business fields

In industrial settings and society overall, situations are often encountered in which it is necessary to find the optimal choice from among a huge number of options. Examples include route planning in logistics, financial portfolio optimization, and molecular design for medicine. These problems are referred to as combinatorial optimization problems. However, it is extremely difficult to solve these problems in a short period of time because of the phenomenon of combinatorial explosion; that is, an exponential increase in the number of possible combinations with the increasing complexity of the problem. This has given rise to expectations for completely new types of computers such as quantum computers.

1. Research and Development

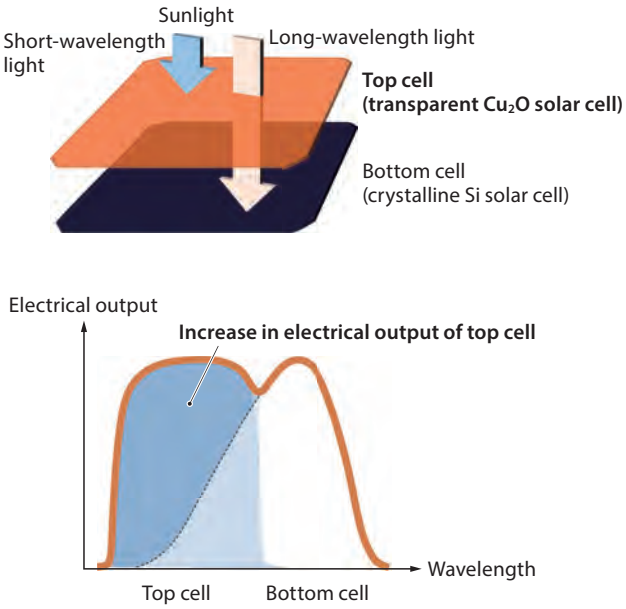
In 2016, Toshiba Corporation theoretically proposed a quantum computer for combinatorial optimization called a quantum bifurcation machine. Building on this theory, we discovered and developed a simulated bifurcation (SB) algorithm in 2018 that makes it possible to solve combinatorial optimization problems using conventional digital computers. While simulated annealing (SA), a typical conventional algorithm, requires sequential updating of variables, the SB algorithm allows simultaneous updating of variables. Therefore, the SB algorithm can solve combinatorial optimization problems very rapidly using state-of-the-art digital computers with high parallelism.

For a 2 000-bit problem, the newly developed SB machine using a field-programmable gate array (FPGA) performs roughly 8 000 computations in parallel, approximately 10 times faster than the worlds' previously fastest machine using lasers(*). Furthermore, for a 100 000-bit problem, our SB machine using a graphics processing unit (GPU) cluster is roughly 10 times faster than the fastest SA implemented with a PC cluster(*). SB makes it possible to realize fast and large-scale combinatorial optimization using FPGAs, GPUs, and other existing parallel computing systems.

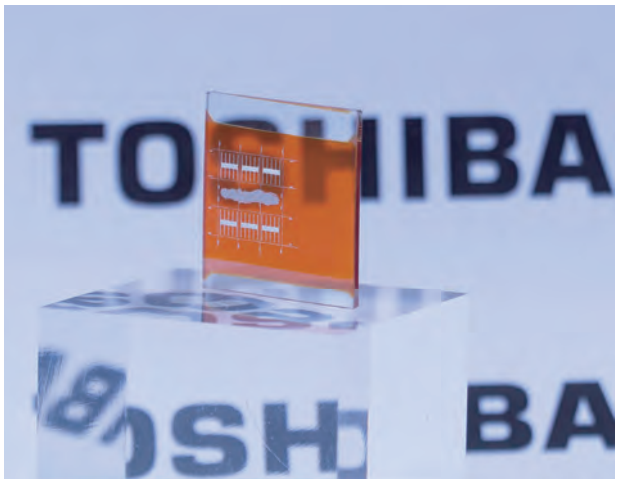
In the near future, we will tackle various social issues using this technology.

(*) As of April 2019 (as researched by Toshiba Corporation)

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



Principle of high-efficiency power generation using tandem solar cell



Transparent cuprous oxide (Cu_2O) solar cell

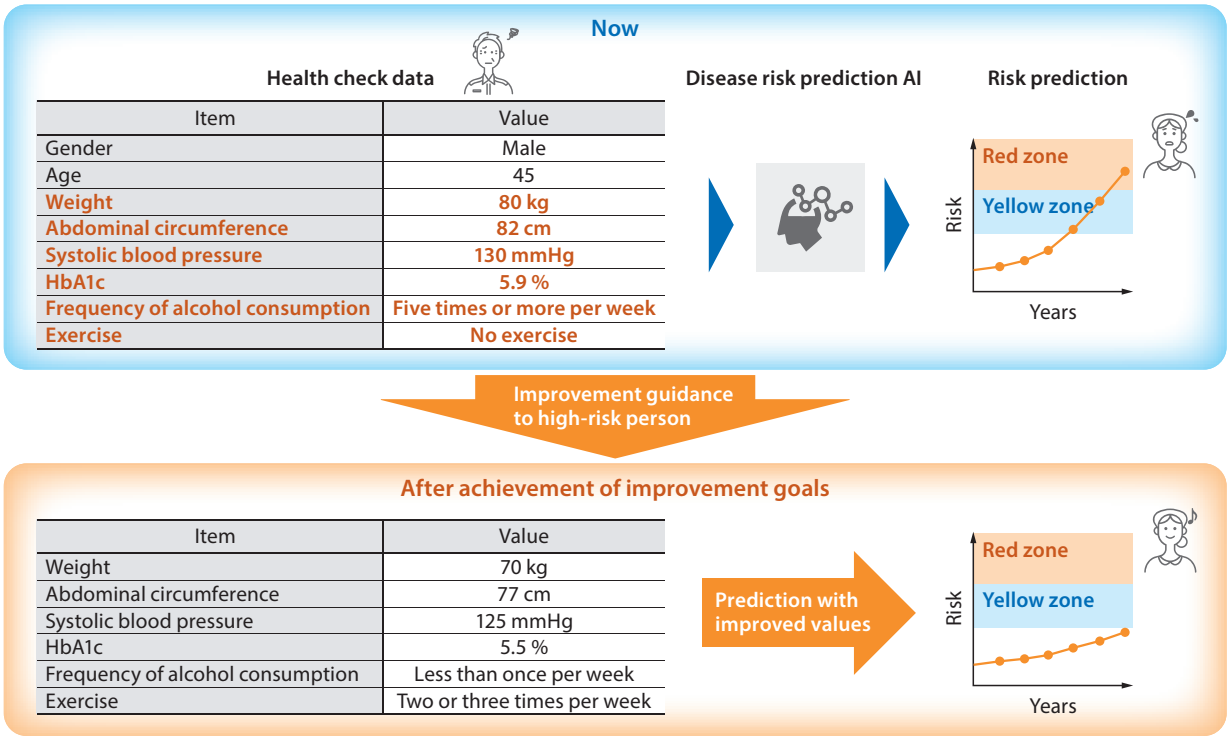
Toshiba Corporation has developed a new low-cost, high-efficiency tandem solar cell with a small footprint that can generate a large amount of electricity. Although high-efficiency tandem (multijunction) solar cells consisting of laminated III–V compound semiconductors such as gallium arsenide semiconductors are already commercially available, their manufacturing costs are currently hundreds to thousands of times higher than those of crystalline silicon (Si) solar cells, making it difficult to apply tandem solar cells to general applications.

The newly developed tandem solar cell consists of a crystalline Si solar cell and the world's first transparent solar cell using low-cost cuprous oxide (Cu_2O)(*). We have realized the transparent Cu_2O solar cell using a unique thin-film formation technology, attaining an efficiency of 24.2% when combined with a crystalline Si solar cell having a power generation efficiency of 22%. Because copper, the principal material of Cu_2O solar cells, is a naturally abundant element, cost reductions can be expected.

We are currently developing tandem solar cells having a power generation efficiency of 30% with a view to creating new businesses by applying tandem solar cells to various products such as home-use solar power systems, distributed power sources, multi-megawatt photovoltaic equipment, and electric mobility solutions.

(*) As of January 2019 (as researched by Toshiba Corporation)

1.26 Lifestyle-Related Disease Risk Prediction Technology Utilizing Health Check Data



HbA1c: hemoglobin A1c

Lifestyle improvement guidance using disease risk prediction technology

Toshiba Corporation has developed a disease prediction technology using data from annual health checks such as height, weight, and blood test results. We will provide a disease prediction service for clinics that offer health check services so that they can contribute to the improvement of people's quality of life (QOL) by giving them appropriate guidance on lifestyle improvement.

The newly developed technology utilizes a random survival forest algorithm, because it is important to show the grounds for predictions during interviews on lifestyle guidance. We have employed a unique optimization technique and AI to learn from anonymized big data provided by the Toshiba Health Insurance Society. As a result, the new algorithm has achieved an area under the curve (AUC)(*1) of more than 0.9 for six-year diabetes risk prediction, which is the world's top level of accuracy(*2).

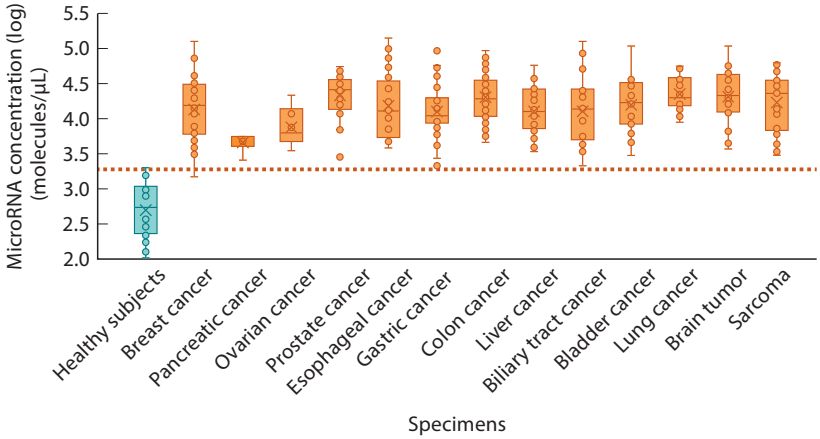
Our next step is to increase the number of diseases supported by the prediction models and develop a prediction technology that takes into account individuals' constitutional predispositions derived from genomic data in collaboration with universities.

(*1) A metric of the two-class separation between the 0 and 1, with values closer to 1 indicating higher accuracy

(*2) As of October 2019 for predictions using health check data (as researched by Toshiba Corporation)

1.27 MicroRNA Detection Technology for Early Cancer Detection through Conventional Blood Tests

MicroRNA chip and compact cancer detection apparatus



Results of microRNA concentration measurements in blood of patients with 13 types of cancer and healthy subjects

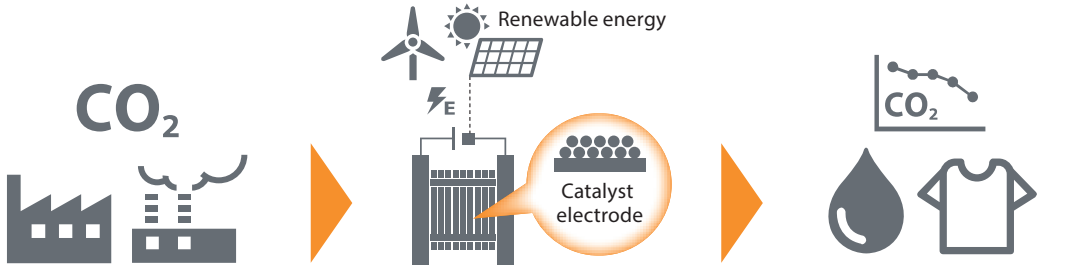
Toshiba Corporation has developed a technology to detect cancer with a high level of accuracy based on the amount of micro-ribonucleic acids (microRNAs) in a single drop of blood. We have confirmed that the newly developed technology achieves 99% accuracy in the detection of 13 types of cancer including colon and pancreatic cancer. We have also obtained results showing the successful detection of several cases of stage 0 cancer, the earliest stage.

This technology uses our unique microRNA amplification technique and microRNA chip. MicroRNAs are molecules essential for the regulation of genes in cells. Tumor cells secrete specific microRNAs into the blood. The new technology consists of a microRNA chip and compact cancer detection apparatus to analyze microRNAs extracted from blood. Since less than two hours is required for an analysis, test results will be available on the same day. Therefore, the new technology is expected to be used at clinics for early detection of cancer through conventional blood tests.

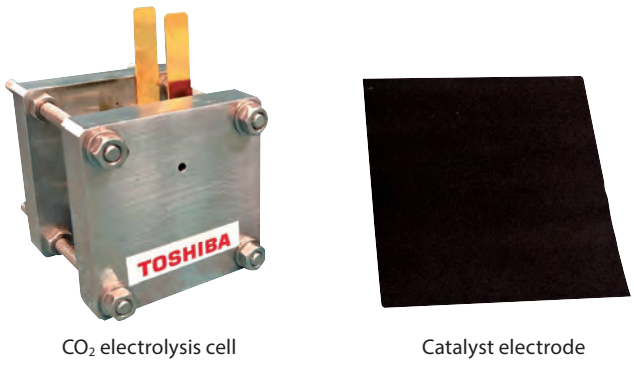
We have conducted joint research with Tokyo Medical University and the National Cancer Center Japan toward realizing clinical application, and have demonstrated that the new technology can distinguish between subjects with cancer and healthy subjects.

This research was partially funded by the Japan Agency for Medical Research and Development (AMED) under Grant Number JP18ae0101014.

1.28 Power-to-Chemicals CO_2 Utilization Technology



Outline of power-to-chemicals concept to produce valuables from CO_2 using renewable energy



CO_2 electrolysis cell and newly developed catalyst electrode

As dependence on fossil fuels remains a major obstacle on the path to a carbon-free society, industry is working on the development of technologies to utilize carbon dioxide (CO_2) as a resource. In this context, power-to-chemicals, a concept of producing bulk chemicals directly from electricity, is attracting a great deal of attention.

Toshiba Corporation has developed a CO_2 electrolysis cell with a catalyst electrode that converts CO_2 into carbon monoxide, a raw material for chemicals and fuel, with the world's highest-class speed(*). This catalyst electrode uses the simultaneous three-phase boundary reactions of the solid (catalyst), liquid (water), and gas (CO_2) phases and provides a highly CO_2-diffusive porous catalyst layer, achieving a 92% Faraday efficiency at a current density of 700 mA/cm^2 under ambient conditions.

This technology helps to reduce the footprint of CO_2 electrolysis systems, which can be powered by solar, wind, and other renewable energy sources. Therefore, power-to-chemicals will become a reality if CO_2 electrolysis systems are installed in the vicinity of industrial facilities, thermal power plants, and other CO_2-emitting facilities.

(*) As of March 2019 (as researched by Toshiba Corporation)

1.29 World's First Field Trial of Real-Time Transmission of Whole-Genome Sequence Data Using Quantum Cryptography

Toshiba Corporation and the Tohoku Medical Megabank Organization (ToMMo) of Tohoku University have succeeded in the world's first quantum cryptography transmission of whole-genome sequence data with data volumes exceeding several hundred gigabytes(*). Quantum cryptographic communication technologies apply the principles of quantum mechanics to realize secure cryptographic communications that are robust against any form of wiretapping or decryption. These technologies are therefore expected to be used to back up confidential data and encrypt medical data transmissions requiring high confidentiality.

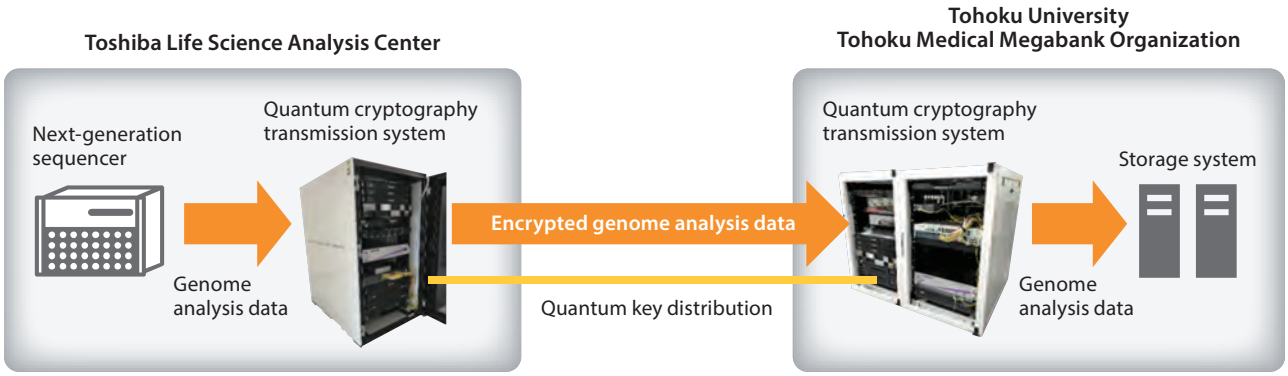
Since speeds for key distribution in quantum cryptographic communication technologies are currently about 10 Mbps at a maximum, the speed at which data can be encrypted and transmitted with a one-time pad is limited. Hence, there is a room for improvement of large-scale data transmission with the one-time pad method. Toshiba and ToMMo developed a new system for sequential encryption and transmission of large-scale data, thereby realizing real-time transmission of whole-genome sequence data with the one-time pad method.

Using this system, Toshiba and ToMMo transmitted data over an approximately 7 km dedicated optical fiber line between ToMMo and the Toshiba Life Science Analysis Center, at which a next-generation sequencer was installed, in Sendai City in July and August 2019. In the field trial, whole-genome sequence data output from the analysis of genome sequences in DNA samples held by ToMMo were able to be sequentially encrypted for quantum cryptography communications with a one-time pad and transmitted in real time without delay following the completion of analysis processing. These results confirmed that quantum cryptography technologies can be practically applied to cryptographic transmission of large-scale, highly confidential genome analysis data.

We will continue our efforts toward practical quantum cryptography for various applications, including medicine, finance, and telecommunications infrastructures.

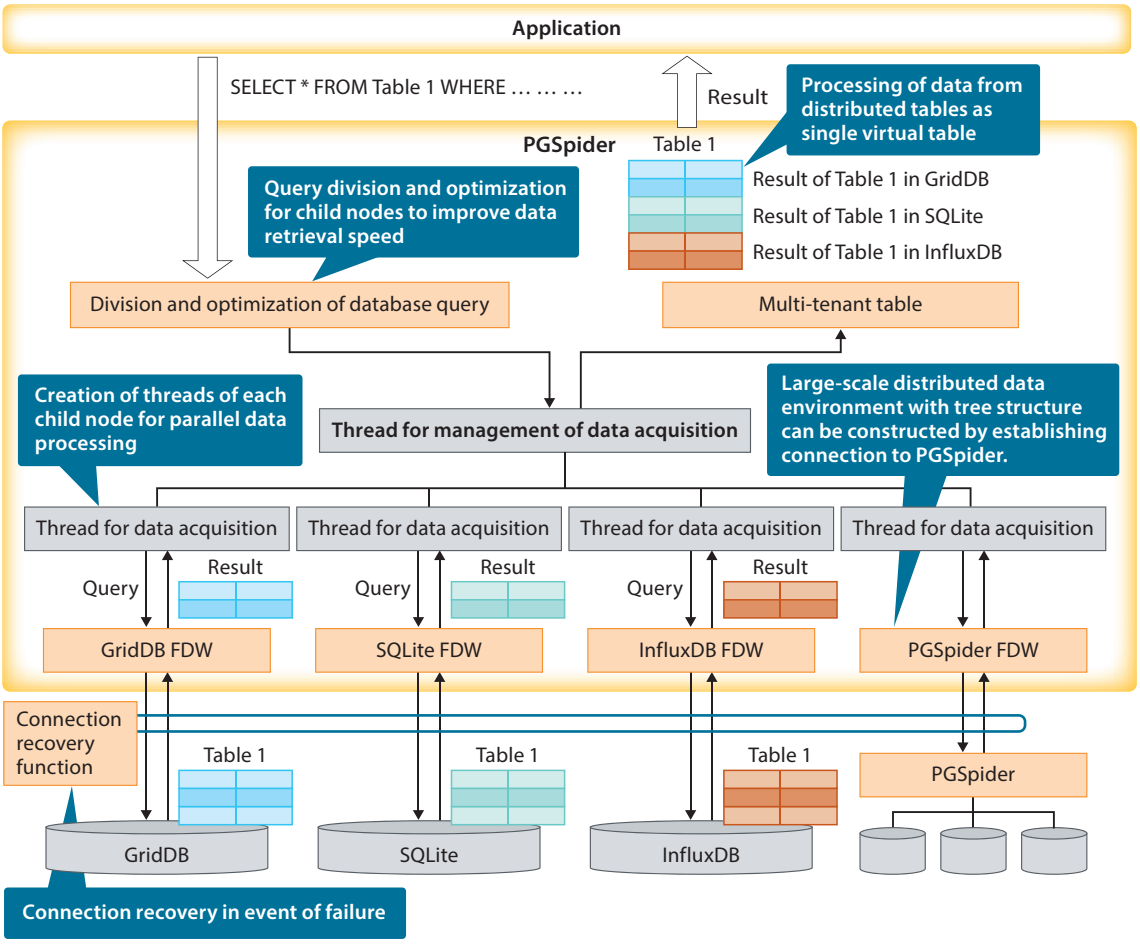
Part of this work was performed under the "Photonics and Quantum Technology for Society 5.0" Cross-ministerial Strategic Innovation Promotion Program (SIP) of the Council for Science, Technology and Innovation (CSTI) (funding agency: QST).

(*) As of January 2020 for quantum cryptographic communication (as researched by Toshiba Corporation)



Overview of newly developed transmission system for genomic information and its field trial

1.30 PGSpider High-Performance SQL Cluster Engine



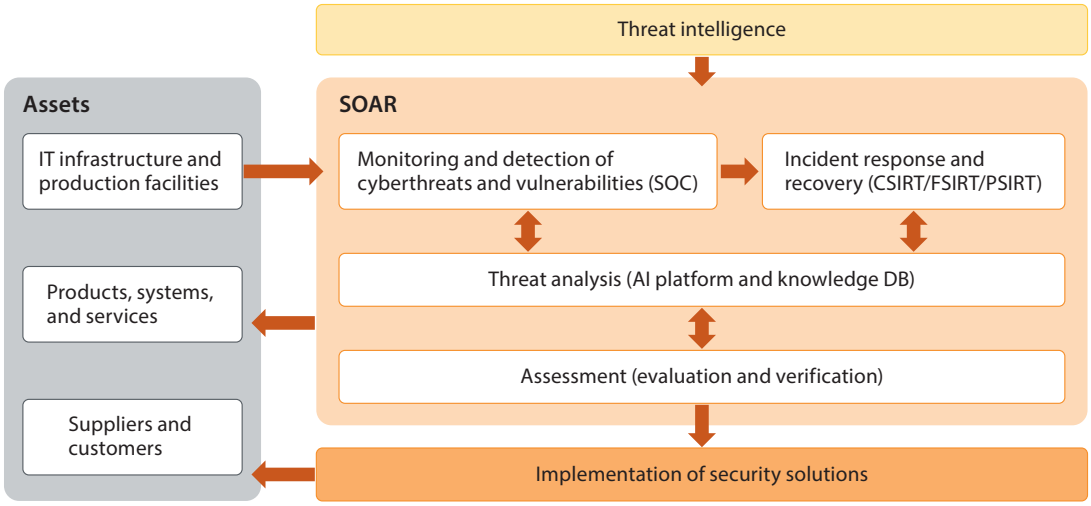
FDW: foreign data wrapper

System architecture of PGSpider high-performance SQL cluster engine

Edge computing involves the use of a large number of sensors and devices that generate vast amounts of data. Systems using edge computing need to aggregate and analyze all of these data to optimize operations. However, aggregating such huge amounts of data is a challenging task.

To overcome this issue, Toshiba Corporation has developed a large-scale distributed Structured Query Language (SQL) engine called PGSpider, which is capable of handling data from distributed edge devices as a single virtual table to achieve high-speed data retrieval. PGSpider is based on PostgreSQL and provides such features as query division and optimization, multi-tenant virtual tables, and parallel data processing. PGSpider also incorporates a connection recovery function that helps to improve the availability of child nodes even under adverse network conditions.

1.31 Cyber Defense Management Platform (CDMP)



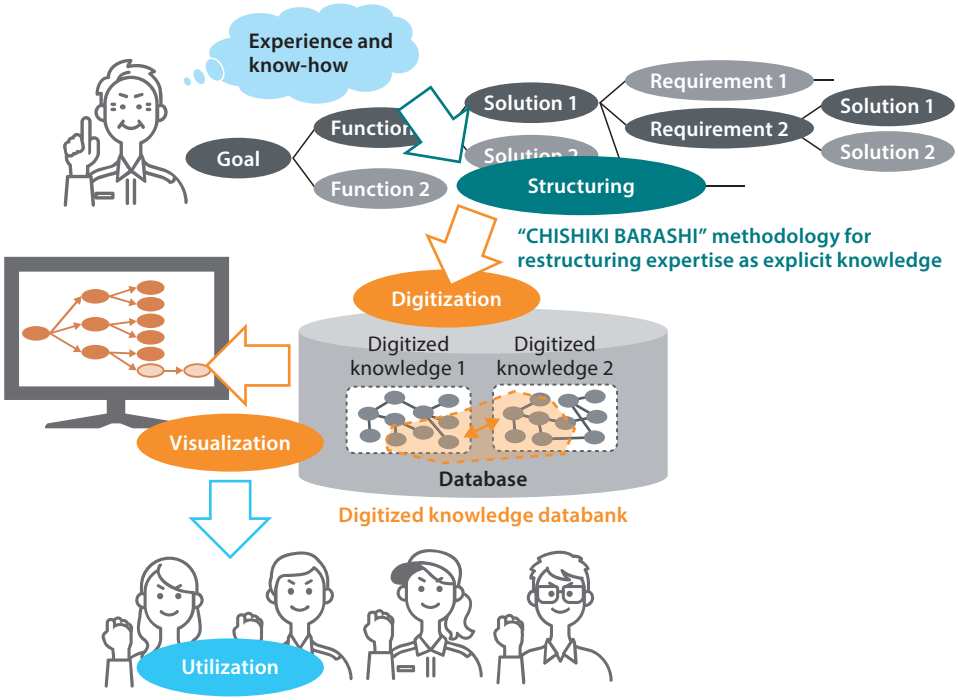
IT: information technology
SOC: Security Operation Center
CSIRT: Computer Security Incident Response Team
FSIRT: Factory Security Incident Response Team
PSIRT: Product Security Incident Response Team
DB: database

Overview of Cyber Defense Management Platform (CDMP) using security orchestration, automation and response (SOAR)

In order to improve the speed and accuracy of risk detection and response in cybersecurity operations, the Toshiba Group is designing a cybersecurity operation platform called the Cyber Defense Management Platform (CDMP). CDMP aims to minimize the impact of cybersecurity risks on corporate activities by utilizing threat intelligence, i.e., information that supports decision-making concerning cybersecurity, including cyberthreat trends and hackers' activities, and by automating monitoring, detection, response, and recovery.

We have begun using the security orchestration, automation, and response (SOAR) function of CDMP to monitor and detect cyberthreats based on threat intelligence. In the near future, we will expand the use of threat intelligence to proactively prevent the occurrence of cyberthreats.

1.32 Methodology and Schema Structure for Digitizing Accumulated Expertise to Improve Productivity



Outline of method for accumulation and utilization of experience and know-how

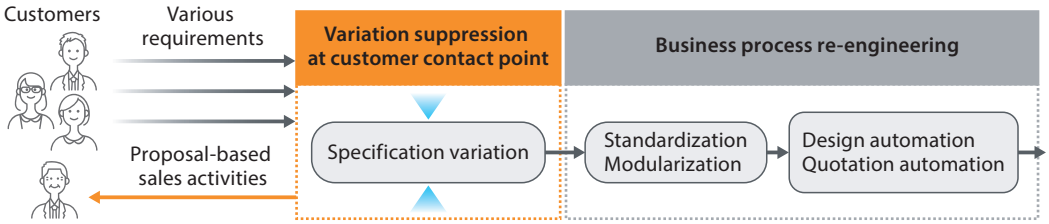
It is no easy task to properly express and share the intricacies of personal experience and know-how in product design and development. This makes it difficult to improve productivity or, in some cases, causes productivity degradation.

Toshiba Corporation has developed a methodology called "CHISHIKI BARASHI" to efficiently organize and visualize technical expertise in the form of explicit knowledge as well as a databank that stores the digitized knowledge in such a manner as to enhance its reusability.

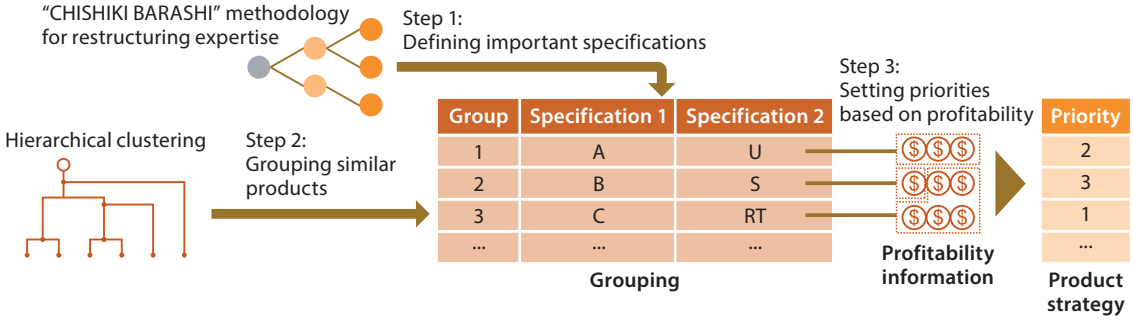
To visualize technical expertise, we have developed multiple templates for each specific purpose, which assist in creating new ideas, reorganizing development processes, and so on. These templates allow facilitators to follow the same procedure to apply the methodology and use the same structure for visualization. The organized knowledge is converted into digital data and stored in a database using a special Resource Description Framework (RDF) schema, which defines the meaning of structured data.

We have also developed a system to visualize digitized knowledge in order to facilitate the creation of new ideas. A database search using a certain keyword returns a wide range of knowledge connected through synonyms, indicating additional keywords for new ideas or key people to be contacted to obtain more information.

1.33 Product Variation Suppression Procedure to Manufacture Products According to Customer Requirements with Short Delivery Time



Product variation suppression at customer contact point



Outline of product variation suppression procedure

Toshiba Corporation has established a methodology for logically creating product strategies, which consists of (1) grouping the specifications of multiple past products based on the results of hierarchical clustering analysis, in conjunction with a methodology called "CHISHIKI BARASHI" for restructuring product design expertise, and (2) selecting markets in which it has significant competitive advantages based on internal profitability information.

Designing each product based on similar existing products wastes time and results in a loss of business opportunities. In order to meet various customer requirements, it is necessary to shift toward proposal-based sales by suppressing specification variations, thereby improving engineering productivity without compromising the value of the product to the customers.

To achieve this goal, we have developed a three-step procedure. The first step is to visualize the value of the product to the customers and define important specifications for the target product by means of "CHISHIKI BARASHI." The second step is to objectively group similar products with important specifications through hierarchical clustering analysis. The final step is to set priorities for each group based on internal profitability information such as production output and gross margin.

We have applied the new methodology to the railway air-conditioner business, consequently dividing 298 models into 15 product groups, each of which has been associated with information about production output. Furthermore, we have re-engineered our business process according to the lineup of the standard models, achieving a shift to a proposal-based sales model.