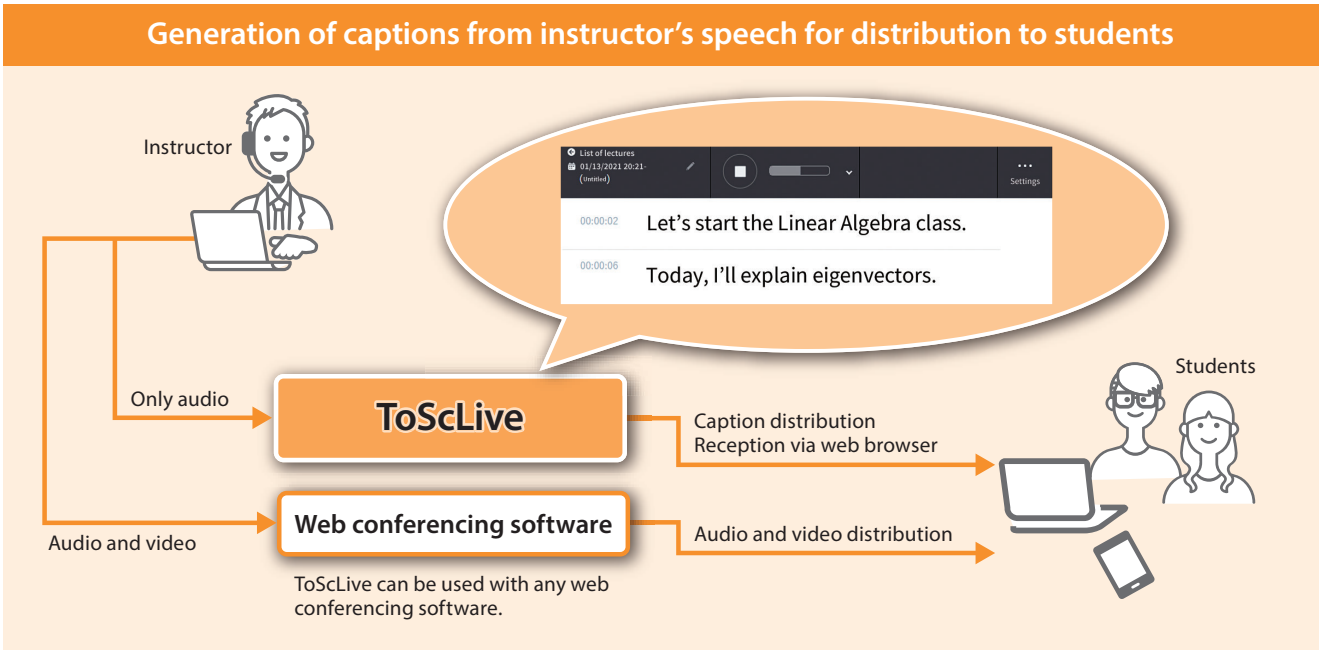
1. Research and Development

1.1 ToScLive Automatic Captioning System



Outline of ToScLive automatic captioning system

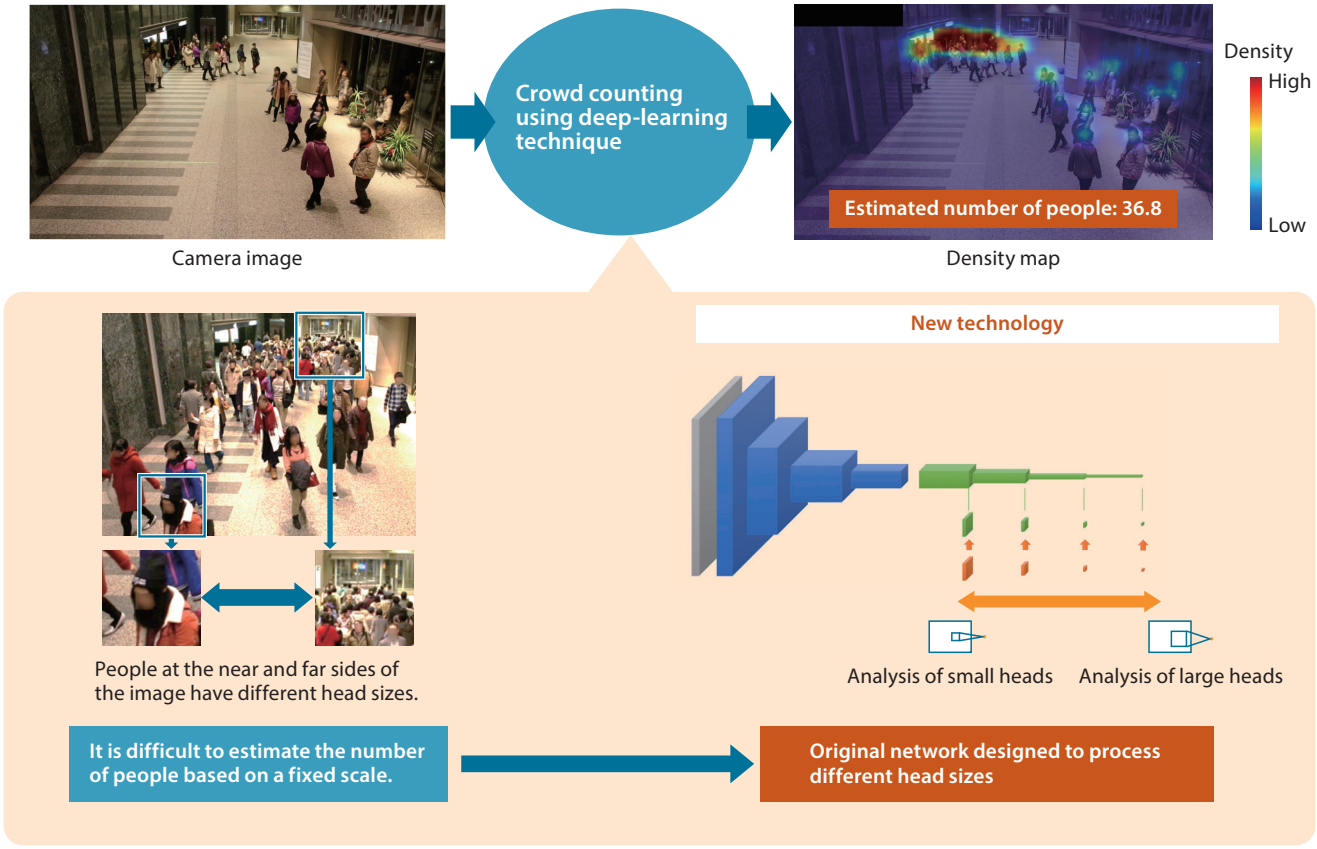
Many university lectures are currently being held online because of the COVID-19 pandemic. However, certain issues are encountered in online lectures such as gaps in the flow of speech as a result of network interruptions and a reduction in the level of students' comprehension due to the difficulty of staying focused in the online lecture environment.

Under these circumstances, Toshiba Corporation has developed an automatic captioning system called ToScLive. Text captions allow students to check any words that they could not catch and to review the contents of a lecture. Real-time speech-to-text conversion thus helps to improve students' comprehension of online lectures.

ToScLive incorporates the latest deep-learning techniques for speech recognition in order to generate captions. A terminology dictionary is necessary to recognize technical terms used in a lecture. Although it is generally extremely costly to manually create a terminology dictionary, ToScLive incorporates a function to extract technical terms from lecture materials automatically as well as a dictionary platform that allows multiple users to coedit the same dictionary. These functions facilitate the creation and sharing of terminology dictionaries, enabling highly accurate generation of captions containing technical terms.

At present, we are conducting demonstration experiments in the Japanese language in collaboration with a number of universities. We will utilize ToScLive to contribute to the realization of a new form of voice communication that will be useful during the COVID-19 pandemic and thereafter.

1.2 Highly Accurate High-Speed Crowd Counting Technology Utilizing General-Purpose PC Processors



Overview of highly accurate high-speed crowd counting technology utilizing general-purpose PC processors

The number of security cameras installed in the world is expected to reach one billion by 2022, and it is anticipated that this figure will increase at an accelerated rate thereafter.

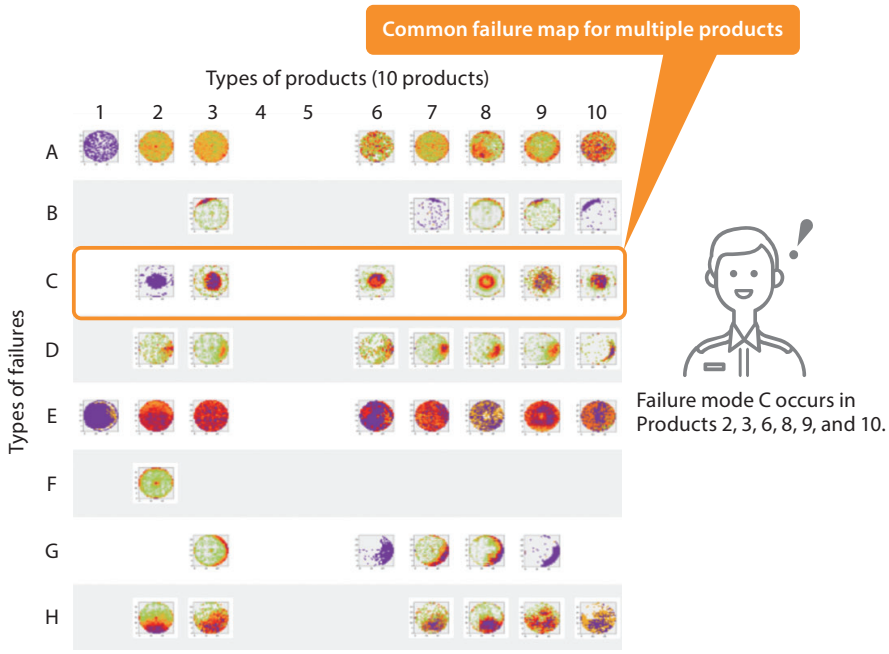
There is a growing need for a means of accurately measuring the number of people and level of congestion at public and commercial facilities such as train stations and airports using images from security cameras, in order to quickly detect congestion that might cause a problem. Moreover, as the world grapples with the COVID-19 pandemic, technologies for detecting crowded conditions quickly and accurately have been attracting much attention.

Although deep-learning techniques can be used to estimate the number of people in crowds with extremely high density, they generally require expensive dedicated computing devices such as graphics processing units (GPUs) because of the huge amount of data to be processed. These techniques are not widely used because of the cost incurred. In addition, since the sizes of people in an image vary by their distance from the camera, it is difficult to obtain an accurate estimate of the number of people in the image.

To solve these issues, Toshiba Corporation has developed a technology that makes it possible to count the number of people in a crowd with high speed and high accuracy using an ordinary PC. First, we developed an original deep-learning technique that can run on a general-purpose central processing unit (CPU) at high speed in order to perform inference processing without the need for a dedicated computing device such as a GPU. We also developed a deep-learning network that can analyze any person in an image regardless of their head size, reducing the estimation error of the number of people per image from 16.0% to 14.7%.

The newly developed technology realizes efficient and low-cost congestion monitoring, especially at facilities with many security cameras.

1.3 Failure Analysis System for High-Mix Low-Volume Semiconductor Manufacturing



Failure visualization system to automatically classify failures common to different products in high-mix low-volume semiconductor manufacturing processes

In modern semiconductor fabrication, artificial intelligence (AI) is utilized for quality data analysis to reduce the time required to identify the causes of failure from a huge amount of data. In high-mix low-volume manufacturing, which is essential to meet diverse customer needs, the AI performance is often degraded because of an insufficient amount of quality data for each product. In addition, it is necessary to repeatedly inspect the results of analysis of the entire mix of products, which is a time-consuming task.

Toshiba Corporation has responded to this situation by developing a comprehensive failure analysis system suitable for high-mix low-volume products. This system integrates failure map(*1) data about various high-mix products into one large dataset to provide the AI with a sufficient volume of data, thereby improving the accuracy of failure classification. In an experiment using WM-811k(*2), we verified that the accuracy of failure classification for 44 products was improved from 75.3% to 83.3%.

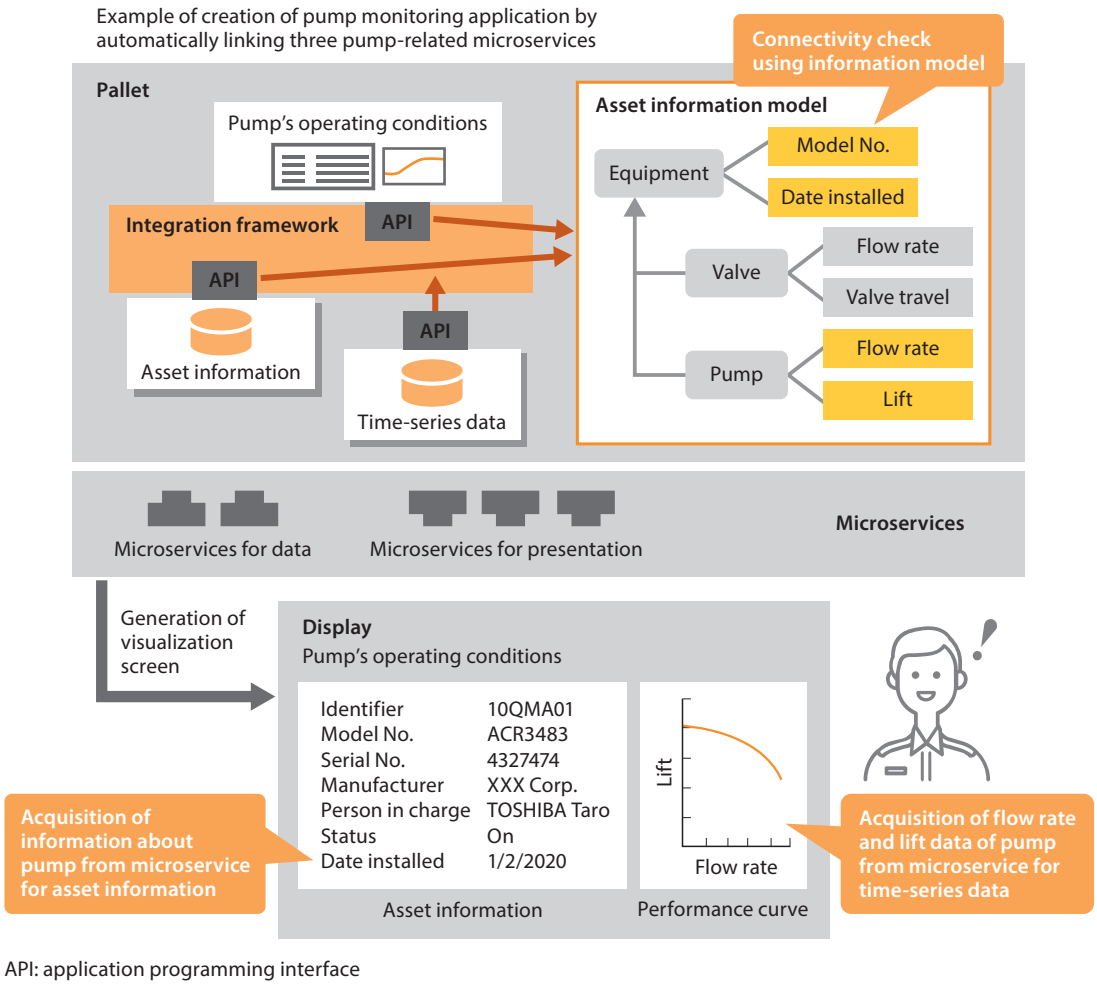
We have also developed a system that efficiently visualizes failure maps common to multiple products so that users can recognize the failure modes at a glance.

We have incorporated the newly developed failure analysis system into the semiconductor fabrication process at the foundries of the Toshiba Group, reducing the time required for failure analysis from 4.2 hours to 0.5 hours per person per day.

(∗1) Binary data representing good and bad chips on a wafer. The number of chips varies with each product.

(∗2) A real semiconductor fabrication dataset available on Kaggle, a data analysis competition platform

1.4 Information Model Based on Application Integration for Microservices



API: application programming interface

Example of microservices integration technique based on information model

In recent years, data have been widely utilized at power plants for efficient operation and maintenance of assets such as turbines. However, since asset names, data types, and units of measurement are inconsistent among the assets, it is necessary to develop analysis and visualization software functions for each plant, incurring additional development time and high non-recurring engineering costs.

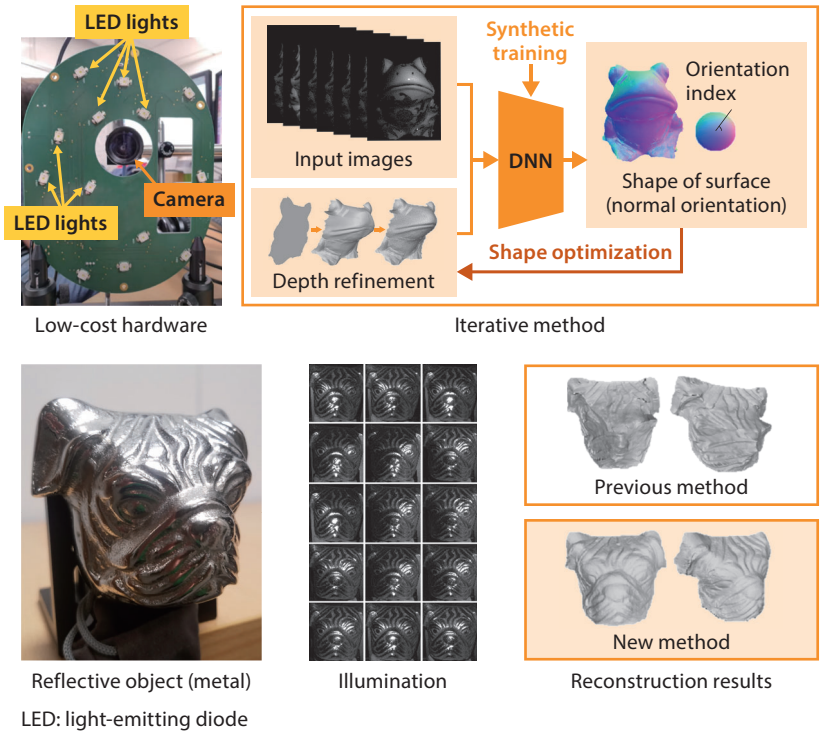
Toshiba Corporation has developed an asset information model using a microservices integration technique in order to modularize microservices as common parts so that new software applications can be rapidly developed simply by combining them.

The asset information model is a data dictionary compliant with the International Electrotechnical Commission (IEC) 61360 and IEC 62656 standards. We are leading the standardization process of these IEC standards, which specify common classes and properties to be used to represent asset information, including names, data types, and units of measurement.

Standardizing asset data with the information model and sharing its semantics among microservices make it possible to check their connectivity automatically. For example, three microservices for a pump related to asset management, time-series data, and visualization, respectively, refer to common properties such as the pump's model number and flow rate. In this case, a pump monitoring application can be created simply by selecting these microservices.

We will incorporate a function for connecting data stored in existing systems into our microservices integration technique so that it will become a key feature for a no-code or low-code development platform for creating new services.

1.5 Accurate Close-up 3D Reconstruction for Reflective Objects



Close-up 3D reconstruction method and results of measurement of reflective metallic object

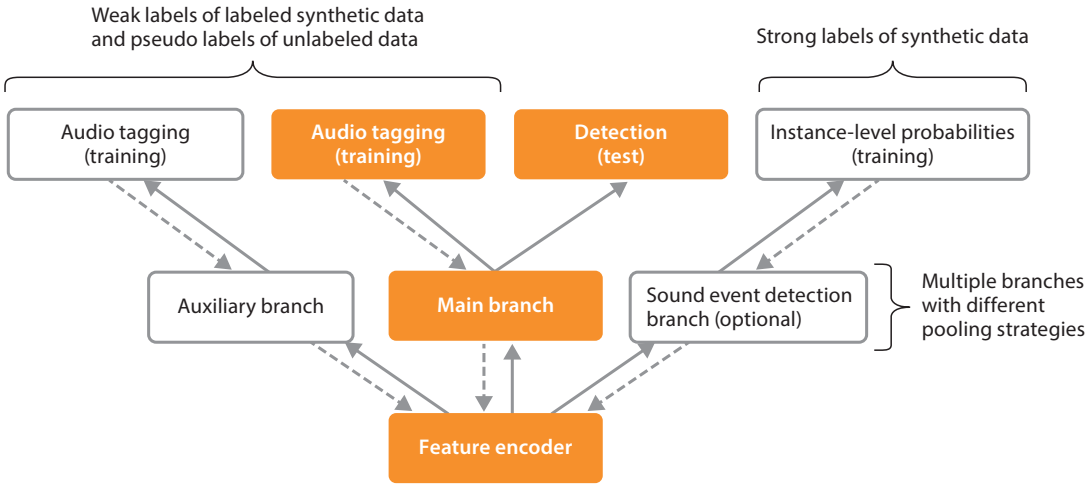
Photometric stereo is a method of computing the three-dimensional (3D) surface geometry of an object by observing it under different lighting conditions. As nonlinear models and optimization techniques have evolved over the past decade, photometric stereo now provides accurate reconstruction of an object when a camera and lights are only a few centimeters away from its surface. Called near-field reconstruction, this technique is popular because of its low-cost hardware, submillimeter accuracy, and applicability to manufacturing inspection processes.

However, one of the most challenging issues remaining to be solved has been the intractably complex computation required to model complicated optical effects from highly reflective objects such as metals, including surface interreflections and other global illumination effects (e.g., shadows and ambient light).

The Cambridge Research Laboratory (CRL) of Toshiba Europe Ltd. addressed this issue using a deep neural network (DNN) trained with a large amount of synthetic training data. The data renderer mimics most relevant physical effects and thus works well in practical situations with real data. The DNN is integrated into the optimization procedure in order to compensate for near-field nonlinearities, thereby achieving an optimal mix of classic optimization and machine learning. As a result, our new method has achieved a 46% reduction in reconstruction error compared with the conventional method. This is the world's first near-field reconstruction method capable of dealing with shiny surfaces(*).

(*) As of September 2020 (as researched by CRL)

1.6 Sound Event Detection Technology



Improvement in performance of sound event detection technology by means of teacher-student model-based guided learning and multi-branch learning

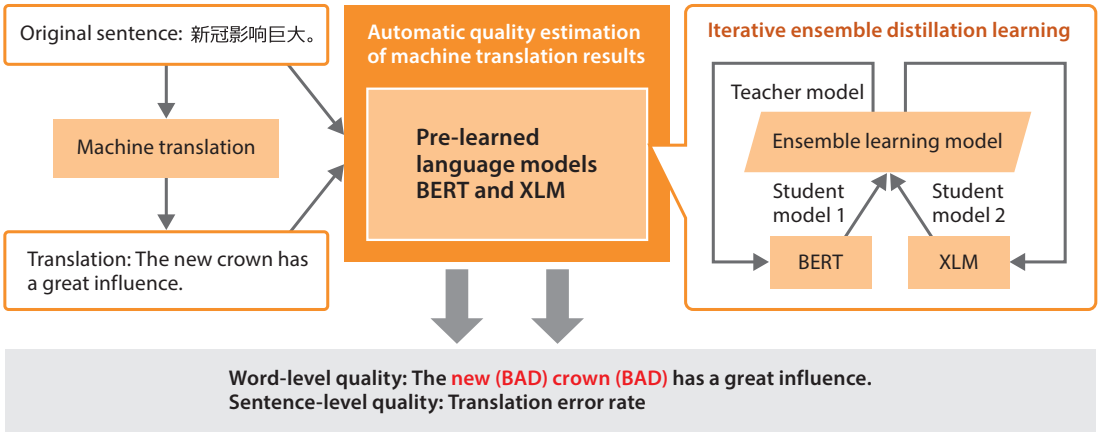
Devices with a voice command interface are becoming increasingly popular because of the COVID-19 pandemic as people can operate them without having to touch any buttons. Sound event detection technology not only provides the convenience of voice control but also facilitates data service businesses aimed at acquiring various behavior logs based on sound while expediting the provision of services according to the users' context.

The Research and Development Center of Toshiba (China) Co., Ltd. is conducting joint research with the Chinese Academy of Sciences on sound event detection technology to recognize users' behaviors and/or surroundings. In order to improve the accuracy of detection of various events in the home environment, we have developed a unique technique that incorporates (1) attention-based guided learning that is composed of a professional teacher model (PT model) and a promising student model (PS model) and (2) multi-branch learning.

The joint team participated in the DCASE2020 Challenge, an international competition in the field of sound event detection sponsored by the Audio and Acoustic Signal Processing Technical Committee (AASP) of the Institute of Electrical and Electronics Engineers (IEEE), and achieved first place with an F-score of 49.5% in the combined sound separation and sound event detection ranking (followed by the 42.3% F-score obtained by the second-ranked participant in this category).

We will actively promote open innovation to further improve the detection accuracy of this technology and achieve practical implementation at an early stage.

1.7 Automatic Machine Translation Quality Estimation Technology



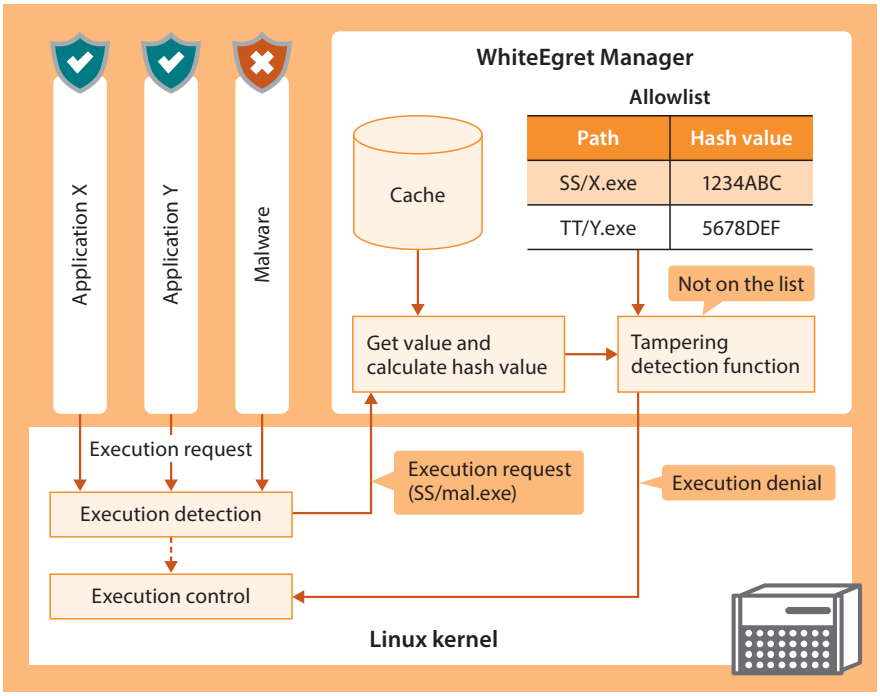
Automatic machine translation quality estimation technology using pre-trained models and iterative ensemble distillation

It is useful to estimate the quality of machine translation (MT) results and to highlight different quality levels with, for example, different colors. It is also crucial to reduce the costs of MT domain adaptation in order to improve translation accuracy by efficiently correcting suboptimal translations and retraining MT models.

The Research and Development Center of Toshiba (China) Co., Ltd. is conducting joint research with Beijing Jiaotong University on automatic MT quality estimation technology. We have considerably improved the accuracy of MT quality estimation, achieving a word-level accuracy of 49.76% and a sentence-level accuracy of 62.48% for Chinese-English translation. (The best results at the 15th China Conference on Machine Translation 2019 were 47.39% and 58.31%, respectively.)

We achieved these results by applying iterative ensemble distillation learning coupled with the state-of-the-art pre-learned language models BERT (Bidirectional Encoder Representations from Transformers) and XLM (Cross-lingual Language Model). We will continue to collaborate with Beijing Jiaotong University to further improve the accuracy of MT quality estimation while developing a novel function for automatically correcting suboptimal translations in order to reduce the costs of post-editing.

1.8 WhiteEgret Malware Protection Technology



Architecture of embedded system equipped with malware protection technology

As the pace of digital transformation accelerates, cyberthreats against critical infrastructure are increasing. Stringent security measures are therefore required for embedded devices and cloud services comprising infrastructure systems so as to allow only authorized applications to be executed.

Under these circumstances, Toshiba Corporation has developed a malware protection technology utilizing allowlists by leveraging standard Linux functions. The new malware protection technology provides the following features:

(1) A hash value is used to detect tampering with executables while a cache function reduces the workload of hash value calculation. As a result, the new technology provides enhanced security and real-time performance.

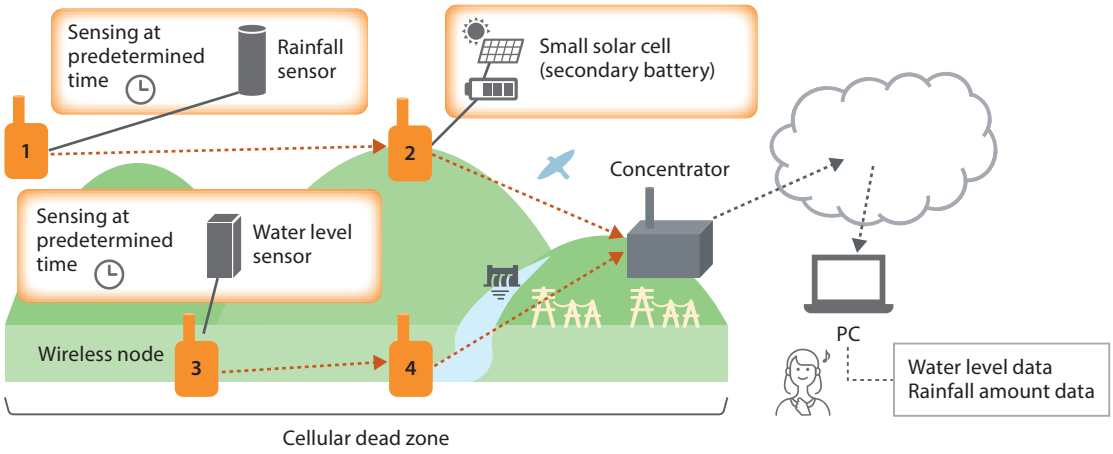
(2) Tampering with an executable image in memory is detected to protect infrastructure systems from fileless malware.

(3) A pathname translator that changes filesystem pathnames according to the Docker namespace supports the Docker application for cloud services.

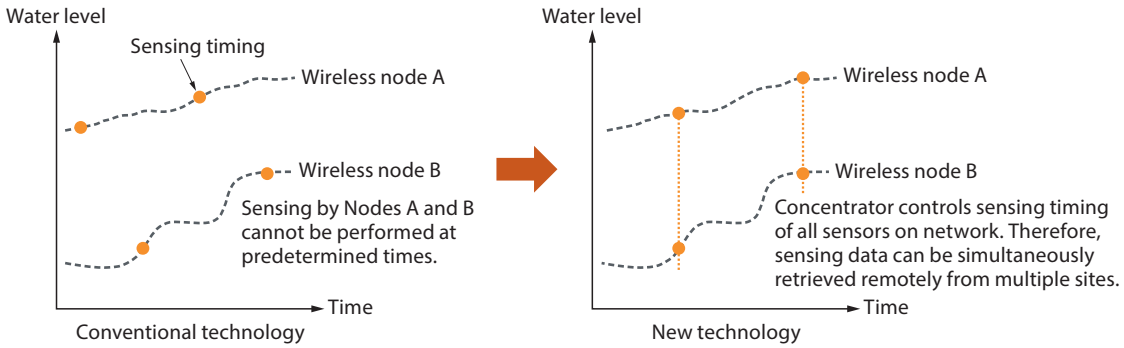
In 2020, we launched SecNucleus WhiteEgret incorporating Feature (1).

Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

1.9 Low-Power Wide-Area Wireless Multihop Networks to Collect Sensing Data at Predetermined Times



River water level and rainfall amount sensing technology using low-power wide-area wireless multihop network



Sensing timing control function to collect data at predetermined times

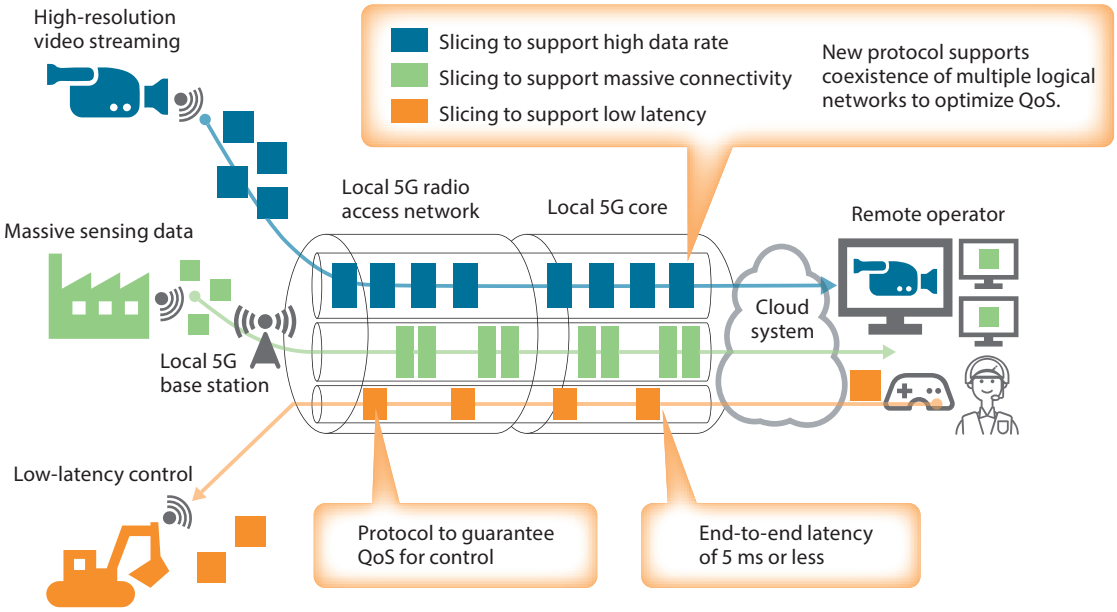
The Internet of Things (IoT) is one of the key technologies that can improve the efficiency of renewable power generation. Many hydroelectric power generation facilities are located outside the reach of mobile phones. To enable the collection of data from sensors located in cellular dead zones, Toshiba Corporation has developed a wireless multihop networking technology that makes it possible to collect sensing data such as the water levels of rivers and amount of rainfall around hydroelectric power generation facilities at predetermined times.

In order to collect sensing data at the predetermined times, reference time information is embedded into packets transmitted from a concentrator. Each sensor in the network computes an expected measurement time based on the reference time information and the preconfigured sensing interval, eliminating the need for complicated management of absolute time.

The newly developed technology also incorporates two new features. First, we have expanded the types of sensor interfaces supported so as to allow the use of off-the-shelf sensors to develop new solutions. Second, we have added support for small solar cells charging a secondary battery, which contributes to the reduction of maintenance costs since solar cells prolong the battery life of the wireless nodes.

Leveraging the newly developed multihop networking technology, Toshiba Energy Systems & Solutions Corporation has launched a power-efficient wireless IoT data solution service called LPIS™. At present, we are planning to apply this technology to control actuators.

1.10 Network Slicing Technology for Local 5G



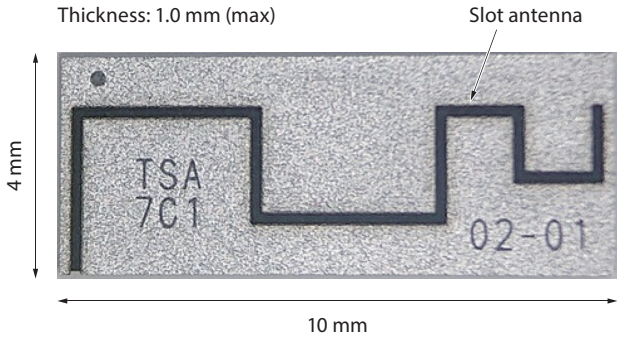
Concept of network slicing technology for local 5G system

Commercial deployment of fifth-generation (5G) cellular networks has commenced. Local (private) 5G deployment in industry is expected to enable customized services that satisfy the requirements of individual business owners and customers in a flexible manner. Network slicing is a key to realizing the coexistence of multiple logical (virtual) networks over a common physical infrastructure. It is crucial to guarantee quality of service (QoS) for high-speed, low-latency, and massive-connectivity communication in factories, warehouses, distribution networks, and other industrial environments.

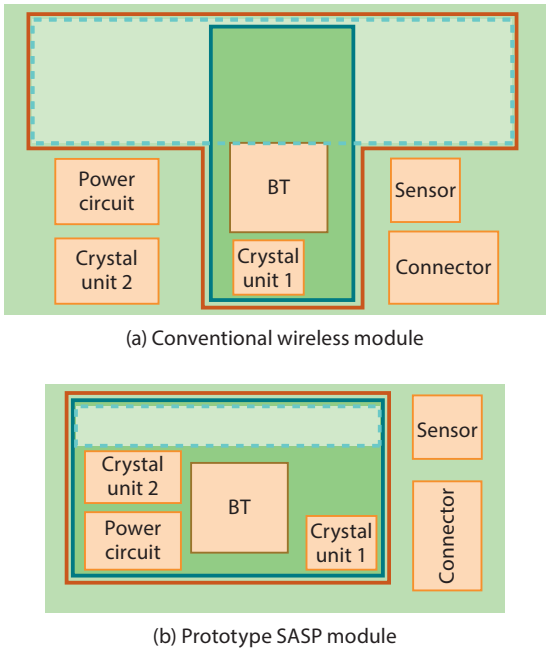
The Bristol Research & Innovation Laboratory of Toshiba Europe Ltd. has developed a network slicing technology for local 5G capable of combining modular and decoupled network functions on different layers of the protocol stack in a dynamic manner according to QoS specifications. The newly developed technology can handle stringent control applications requiring strict isolation among slices. Under a real 5G setup, we have confirmed that the new technology can provide end-to-end latency of 5 ms or less in a local deployment.

We will develop local 5G systems for programmable and scalable virtual 5G networks that support a number of services and solutions, including stable and safe robot control with real-time video or sensory feedback.

1.11 Ultrasmall Bluetooth® Module Equipped with Slot Antenna



Prototype Bluetooth® module fabricated using proprietary SASP technology



Comparison of occupied area on boards of conventional and newly developed wireless modules

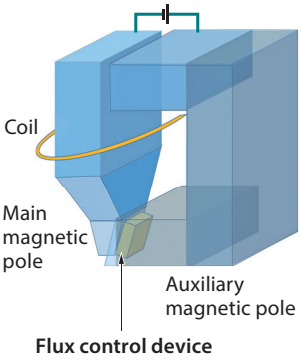
Accompanying the spread of the IoT, small antenna-integrated wireless modules are attracting attention as a means of simplifying board design. Conventional wireless modules require a keep-out zone in which neither wires nor components can be placed in order to obtain the appropriate performance from an antenna. Therefore, conventional wireless modules occupy a board space considerably larger than the actual module size.

To solve this issue, Toshiba Corporation has developed a Bluetooth® 5.2-compliant ultrasmall antenna-integrated wireless module certified by the Telecom Engineering Center (TELEC) of Japan. We have utilized our proprietary slot antenna on shielded package (SASP) technology to achieve the world's smallest occupied board area of 40 mm^2 including the keep-out zone(*) without compromising the antenna performance. The electromagnetic interference between the antenna and surrounding components is so low that it is possible to place components around the wireless module, and even on the other side of the board. In addition, the new wireless module incorporates all the components of a wireless circuit, making Bluetooth® communication possible simply by connecting a battery.

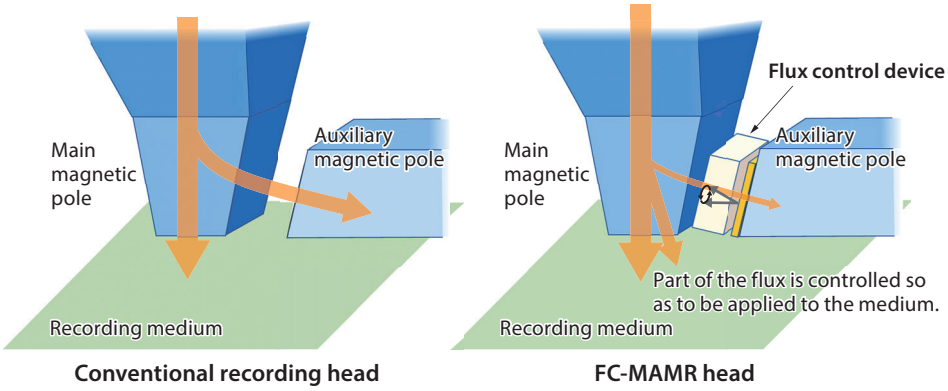
This wireless module will simplify wireless design, contributing to shortening of the development period of small IoT devices.

(*) As of January 2021 (as researched by Toshiba Corporation)

1.12 FC-MAMR Technology for Nearline HDDs to Increase Recording Capacity



Magnetic flux control device positioned between main and auxiliary magnetic poles at tip of magnetic recording head



Enhancement of recording field achieved by controlling magnetic flux between main and auxiliary magnetic poles

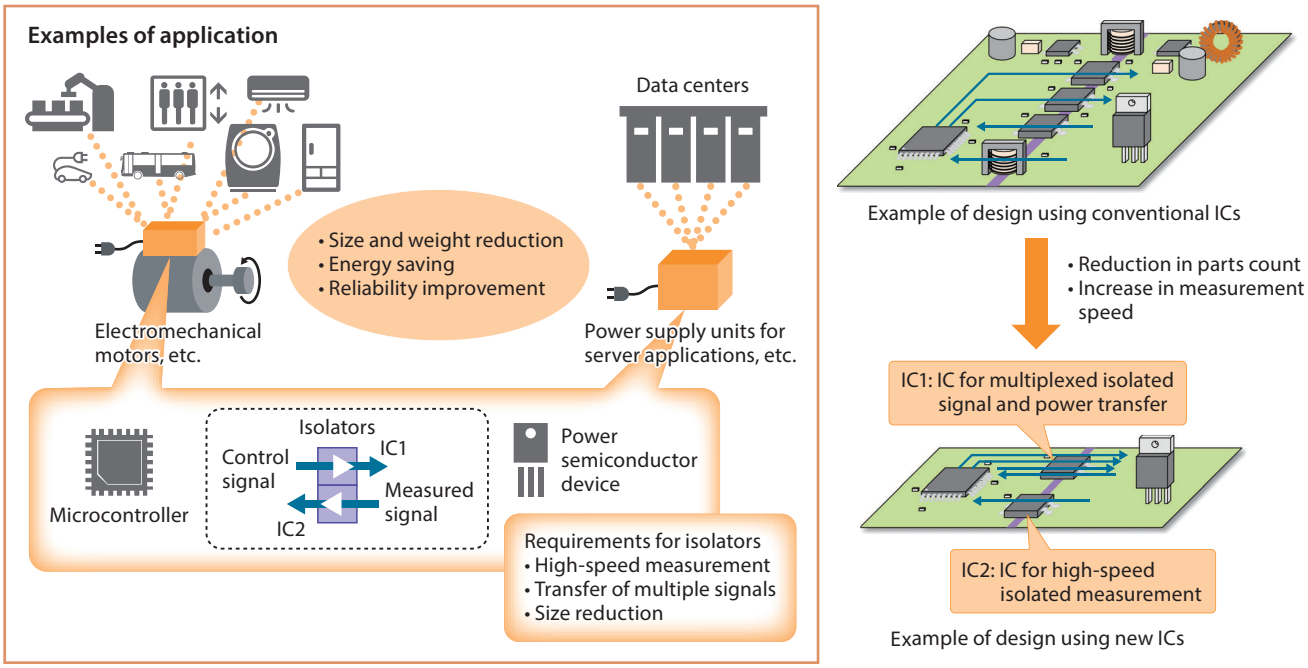
Microwave-assisted magnetic recording (MAMR) is a focus of expectations as a candidate technology to increase the recording capacity of nearline hard disk drives (HDDs) for data centers. In order to accelerate the commercialization of MAMR HDDs, Toshiba Corporation has developed a variant type of MAMR technology called flux control-MAMR (FC-MAMR).

As a consequence of the ever-increasing capacity of HDDs, the size of the main magnetic pole in recording heads and the size of data bits have been becoming progressively smaller at the expense of the writability of the recording heads. It is therefore becoming difficult to further increase recording density through scaling.

MAMR improves the writability of recording heads by applying a microwave magnetic field generated by a device near the main magnetic pole onto the recording medium during magnetic recording. However, MAMR technology requires the development of a dedicated medium to enhance the magnetic resonance with the applied microwave magnetic field, which tends to make the microwave-assisting effect unstable. This remains a challenge to be overcome in order to realize the early commercialization of MAMR HDDs.

The newly developed FC-MAMR technology eliminates the need to design a dedicated medium. With FC-MAMR, a magnetic flux control device positioned between the main and auxiliary magnetic poles uses spintronic technology to reverse the magnetic direction with respect to the magnetic flux generated between these magnetic poles. In this way, part of the flux is applied to the medium to enhance the recording magnetic field. FC-MAMR provides great flexibility in the combination of heads and media, which is expected to facilitate the early commercialization of MAMR HDDs.

1.13 Electromagnetically Coupled, Galvanically Isolated IC Technologies Contributing to Size Reduction and High-Speed Operation of Power Electronic Systems



Electromagnetically coupled, galvanically isolated IC technologies contributing to size reduction and high-speed operation of power electronic systems

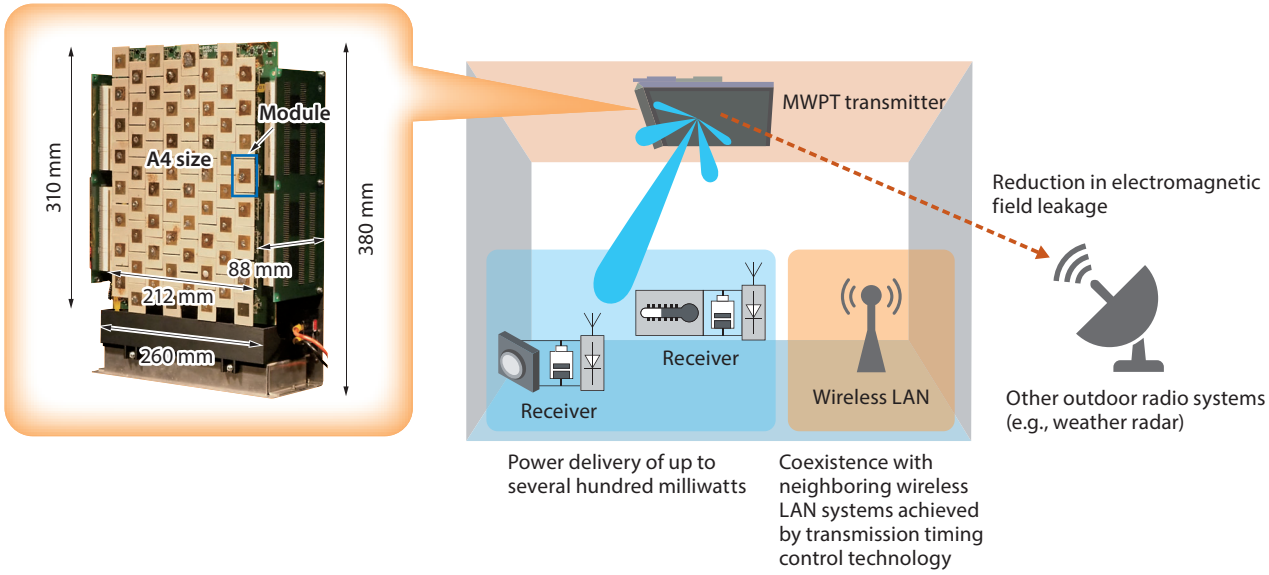
Toshiba Corporation has developed two technologies for galvanically isolated ICs using electromagnetic field coupling with the aim of contributing to the realization of next-generation power electronic systems that are compact, lightweight, energy-efficient, and highly reliable.

The first IC technology concerns multiplexed isolated signal and power transfer that will help to reduce the size and improve the reliability of electric mobility and other motor systems. Fabricated without any manufacturing processes specific to galvanically isolated ICs(*), this newly developed IC can simultaneously transfer three types of signals and more than 100 mW of power when it is placed in such a manner as to cause low electromagnetic interference. This IC helps to reduce the size of a printed circuit board (PCB) compared with the conventional technology for high-performance PCBs.

The second IC technology concerns the high-speed isolated measurement of electric currents in power supply units for data center servers requiring high-speed operation. This newly developed IC incorporates a passive mixer circuit for wireless communication in order to achieve high-speed operation with low power consumption. In addition, we have developed a dedicated calibration circuit to improve current transfer accuracy. As a result, this IC has achieved a measurement speed more than 300 times faster than that of conventional ICs.

(*) For example, deposition of a thick insulation layer on an IC for the prevention of dielectric breakdown

1.14 Microwave Wireless Power Transmission Technology for Realization of IoT Devices Requiring Neither Battery Replacement nor Power Cable



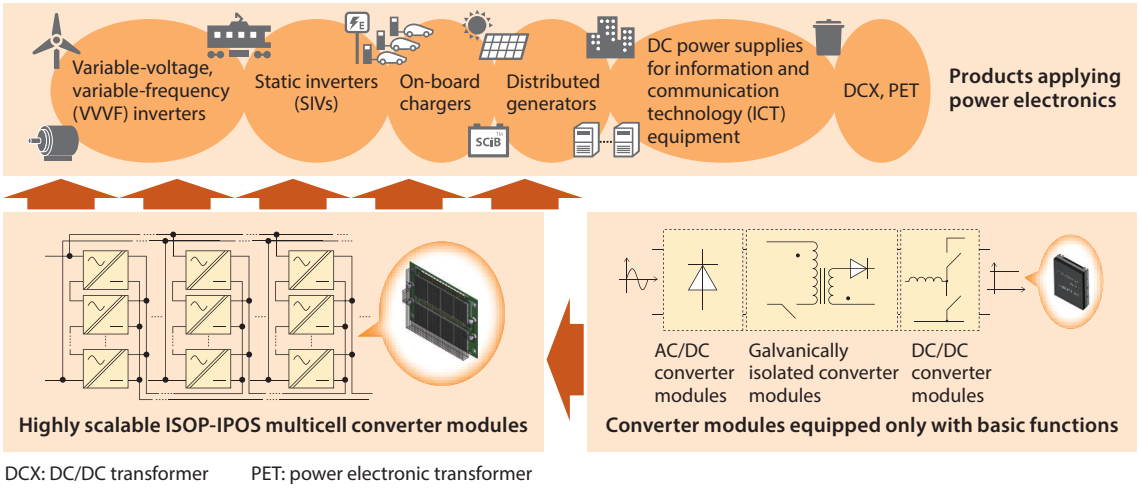
Microwave wireless power transmission (MWPT) system using A4-size power transmission equipment

Microwave wireless power transmission (MWPT) technology to deliver energy over a distance of several meters is attracting attention as a means of realizing IoT devices that require neither battery replacement nor a power cable. However, because of the relatively high level of power transmitted, MWPT systems can potentially interfere with other radio systems and have a detrimental effect on the human body.

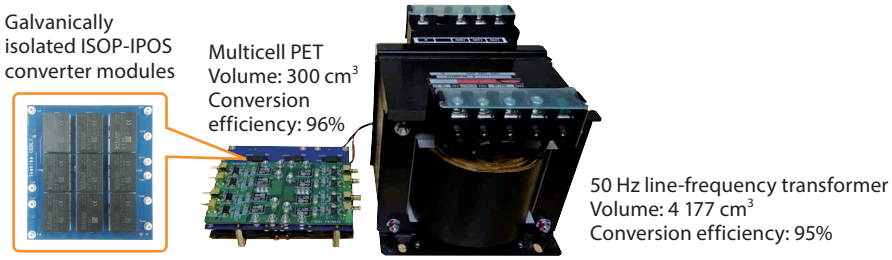
To solve these issues, Toshiba Corporation has developed a transmission timing control technology to detect wireless LAN signals in the adjacent frequency band in order to avoid radio interference, enabling power delivery without disrupting wireless LAN communications. Moreover, we have reduced the size of the transmitter and minimized unwanted radiation by staggering an array of transmission antennas (grating lobes). An MWPT transmitter capable of delivering 1 W over a distance of 2 m is housed in an A4-size casing. We have been leading the legislation process for 5.7 GHz MWPT systems in Japan, completing the publication of the first expert report.

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

1.15 Scalable Multicell Converter Modules for Future Power Electronic Systems



Design concept of power converters using scalable multicell converter modules



Effects of application of scalable multicell converter modules to commercial-frequency transformer

Green products such as photovoltaic solar generators and electric vehicles incorporate a large number of power electronic converters with a wide range of voltage and current ratings. The widespread use of green products will contribute to the realization of a zero-carbon society. It is therefore necessary to develop small, high-efficiency converters with various ratings and to swiftly achieve their commercialization.

Under these circumstances, Toshiba Corporation is developing scalable multicell converters with an input-series output-parallel (ISOP)–input-parallel output-series (IPOS) topology, which features high conversion efficiency and ultrasmall size. These converters are specifically designed to provide basic functions such as AC/DC conversion, galvanic isolation, and DC/DC voltage transformation. They eliminate the complicated and time-consuming process required to create a voltage- and current-balancing circuit for multiple modules, simplifying the development of power converters with various ratings.

We have now developed a prototype multicell power electronic transformer composed of nine 48 V, 150 W ISOP-IPOS converter modules. With only 1/14th the volume of a commercially available line-frequency transformer, this prototype achieves up to 1.0% improvement in conversion efficiency.

1.16 New Algorithms Dramatically Enhancing Speed, Accuracy, and Scale of Simulated Bifurcation Machine™

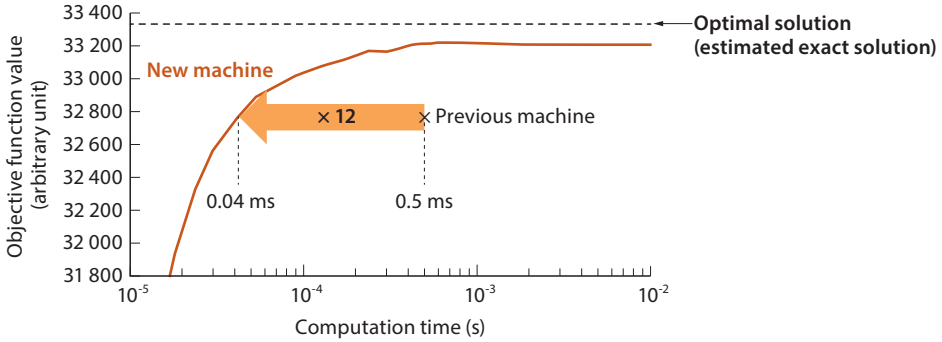
Toshiba Corporation and Toshiba Digital Solutions Corporation have developed two novel algorithms to enhance the speed, accuracy, and scale of the Simulated Bifurcation Machine™, which is designed to solve combinatorial optimization problems in various fields including drug development, logistics management, and portfolio management. These algorithms have been derived from the simulated bifurcation algorithm proposed by Toshiba Corporation in 2019.

One of the two algorithms is designed to quickly find highly accurate approximate solutions. When implemented on a field-programmable gate array (FPGA), it achieved 12 times the speed of our previous machine.

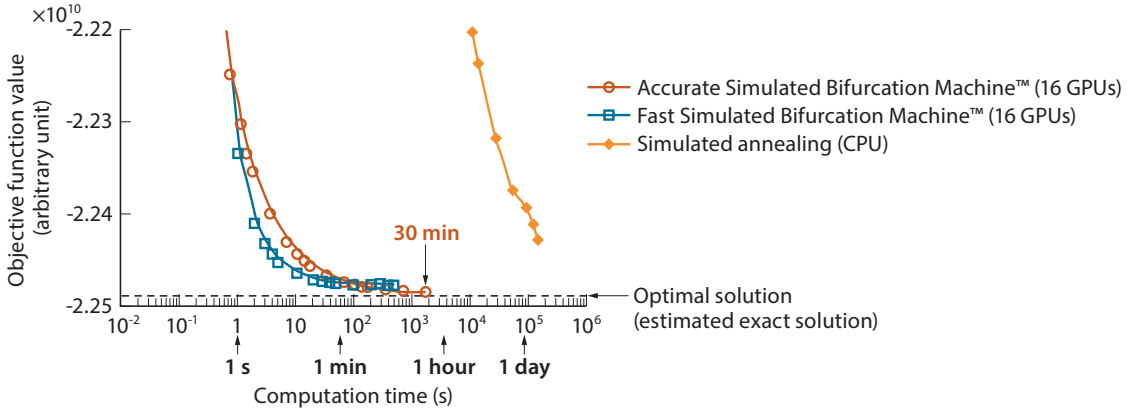
The other algorithm is designed to find more accurate solutions. When implemented on a cluster of 16 GPUs, it reached a close to optimal solution of an ultralarge problem with one million variables in 30 minutes. Approximately 14 months would be required for an algorithm called simulated annealing to achieve the same result when executed on a CPU.

We will offer FPGA-based on-premises services and GPU-based cloud services by the end of 2021.

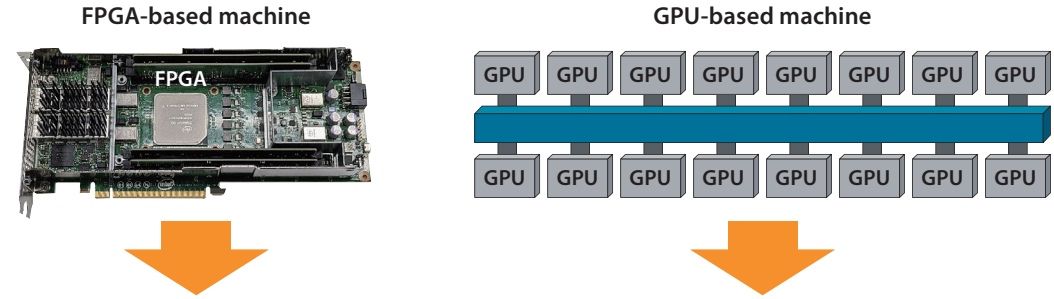
1. Research and Development



Performance of FPGA-based Simulated Bifurcation Machine™

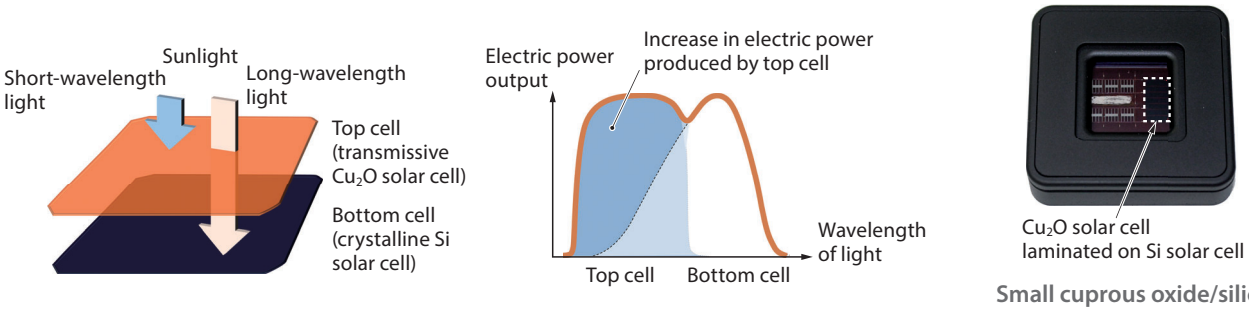


Performance of GPU-based Simulated Bifurcation Machine™



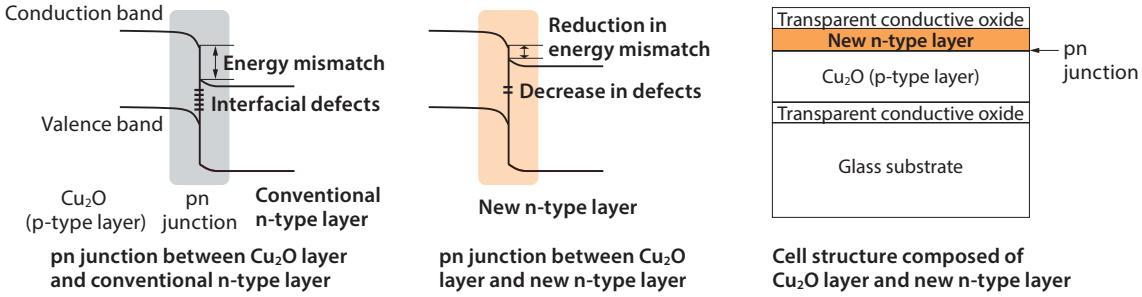
Services of Simulated Bifurcation Machine™

1.17 High-Efficiency Tandem Solar Cell Realized by Improving n-Type Layer of Cu_2O Top Cell



Principle of high-efficiency power generation with tandem solar cell

Small cuprous oxide/silicon (Cu_2O/Si) tandem solar cell



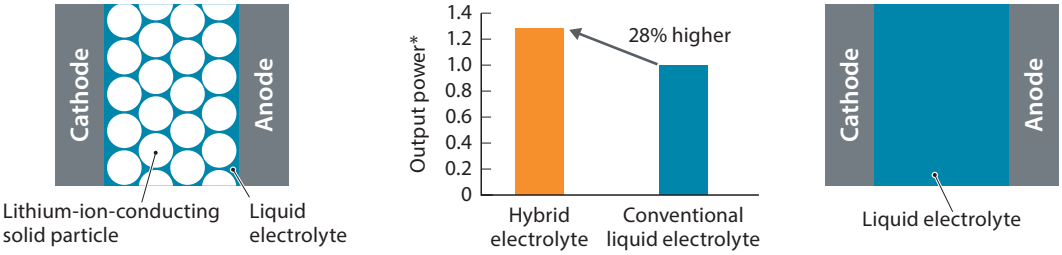
High efficiency achieved by improving n-type layer of Cu_2O solar cell

Toshiba Corporation successfully developed a new low-cost, high-efficiency tandem solar cell in 2019, which can generate a large amount of electric power in a small installation area. The newly developed tandem solar cell is composed of a transmissive solar cell with a p-type cuprous oxide (Cu_2O) layer and a crystalline silicon (Si) solar cell. The transmissive Cu_2O cell, a key component of this tandem solar cell, includes copper and oxygen, both of which are abundant on Earth.

A new n-type layer in the Cu_2O cell helps decrease the energy mismatch at the junction between the p-type and n-type layers, increasing the conversion efficiency of the Cu_2O cell from 6.6% to 8.1%. The tandem solar cell exhibits an overall conversion efficiency of 26.1%, which is 3.1 percentage points higher than the efficiency of the Si cell alone.

According to a report by the New Energy and Industrial Technology Development Organization (NEDO) of Japan, self-charging electric vehicles can be realized by using photovoltaics with a conversion efficiency of 31% or more. We are currently developing tandem solar cells with such an efficiency with the aim of completing the work within three years. In the future, we will create new businesses for electric mobility applications and wide-area distributed power sources.

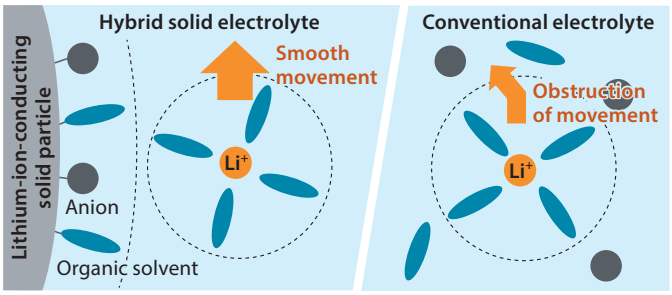
1.18 Hybrid Solid Electrolyte for High-Power Rechargeable Batteries



Battery using hybrid solid electrolyte | Comparison of output power (-20°C) | Conventional battery

* Normalized with output power of battery using conventional electrolyte set to 1

Comparison of output power of batteries containing conventional liquid electrolyte and hybrid solid electrolyte consisting of solid electrolyte particles and organic liquid electrolyte



Li⁺: lithium ions

Mechanism of lower resistance of hybrid solid electrolyte compared with conventional liquid electrolyte

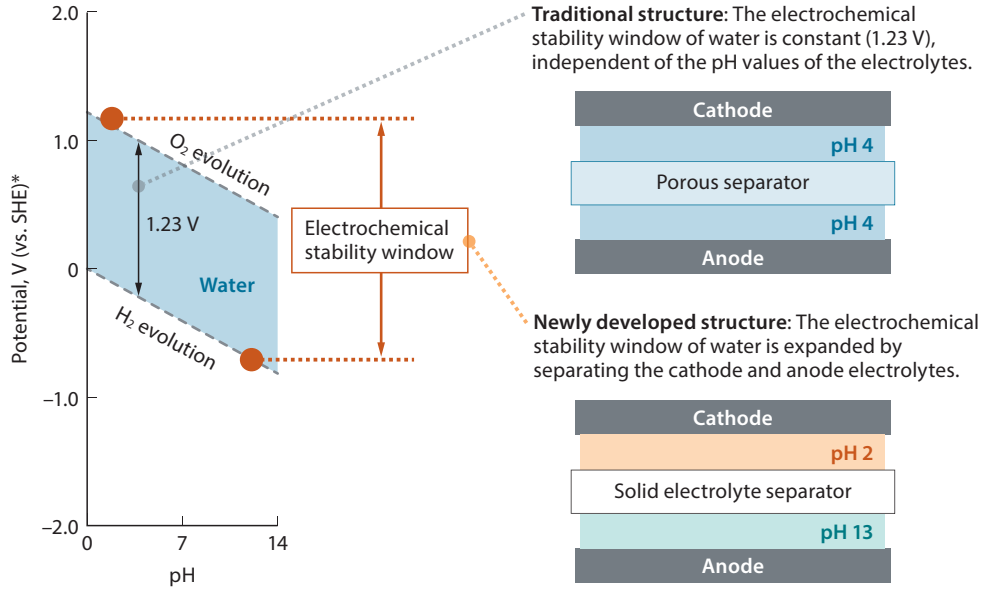
To meet the growing need for the electrification of various mobility and infrastructure systems to help realize a carbon-neutral society, demand is increasing for batteries that can be charged and discharged with a large current over a wide temperature range.

Toshiba Corporation has developed a high-power battery technology using a hybrid solid electrolyte consisting of lithium-ion-conducting solid particles and a liquid electrolyte for the first time in the world(*). At a temperature of -20°C, a battery using the newly developed hybrid solid electrolyte provides 28% higher output power than one using the conventional liquid electrolyte.

In conventional electrolytes, organic solvents and anions hinder the movement of lithium ions, increasing the internal resistance and reducing the output power of the battery. On the other hand, we found that the lithium-ion-conducting solid particles in the new hybrid solid electrolyte attract some of the organic solvents and anions, allowing the lithium ions to move more smoothly. The new battery technology thus helps to reduce the internal resistance and increase the output power of the battery.

(*) As of March 2015 for high-power batteries using a hybrid solid electrolyte (as researched by Toshiba Corporation)

1.19 Aqueous Lithium-Ion Battery with Enhanced Safety



* The working potential in reference to the standard hydrogen electrode (SHE)

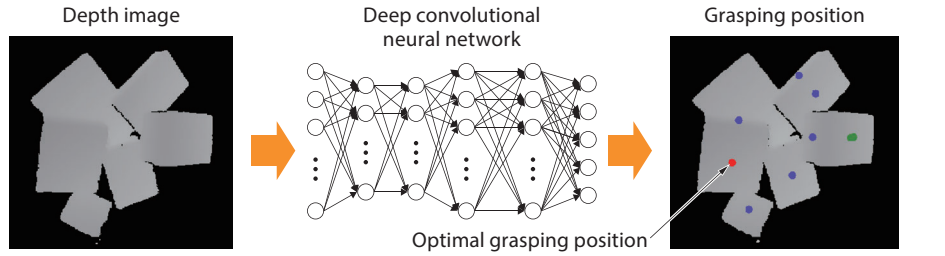
O_2: molecular oxygen
H_2: molecular hydrogen

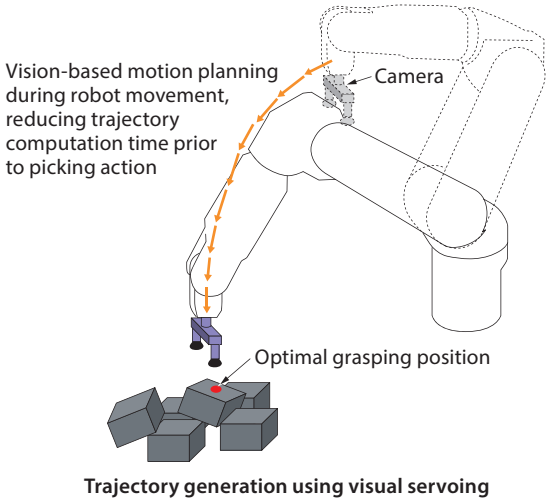
Expansion of electrochemical stability window of water by applying proprietary battery structure using solid electrolyte separator

Conventional lithium-ion batteries are a potential fire hazard because they use a flammable organic solvent to achieve high operating voltage. In recent years, aqueous lithium-ion batteries have been attracting attention because of their low risk of fire caused by external factors. It is difficult, however, to achieve a high operating voltage with aqueous batteries because the electrochemical stability window of the aqueous electrolytes is narrower than that of the organic electrolytes that are typically used in conventional lithium-ion batteries.

Toshiba Corporation has developed a solid electrolyte separator as a solution to this issue. Located between the cathode and anode, this separator makes it possible to achieve a relatively high operating voltage with aqueous electrolytes. The new battery structure with a solid electrolyte separator expands the electrochemical stability window because it prevents hydrogen ions from migrating from the cathode to the anode while enabling the use of two electrolytes with different pH values for the cathode and the anode. In addition to its enhanced safety, the newly developed aqueous lithium-ion battery is expected to be less costly than conventional lithium-ion batteries because it will become possible to simplify manufacturing and safety equipment.

1.20 High-Speed Picking Technologies for Warehouse Robots





Robotic picking technologies for high-speed determination of grasping point and trajectory

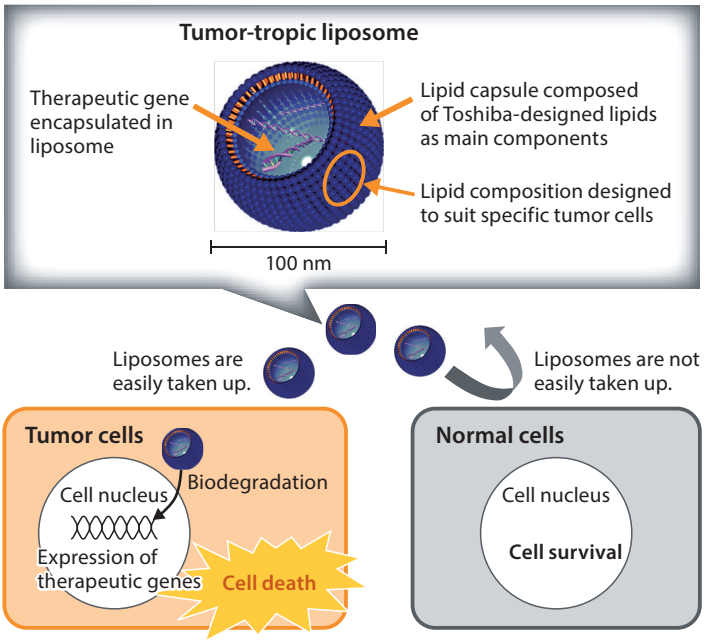
Against the background of growing labor shortages due to the aging of the population in Japan, Toshiba Corporation is developing a picking robot for warehouses. In general, picking robots recognize the type and shape of an object based on a camera image, determine a grasping position, and perform motion planning to generate a motion trajectory prior to the picking action so that the robot hand reaches the position to grasp the target object. In order to shorten the computation time required for these processes, it is effective to increase the speed of grasping position determination and trajectory generation.

Toshiba Corporation has developed a deep convolutional neural network to rapidly determine a grasping point that the robot hand can reach without colliding with any adjacent items or the bin. To further reduce the computation time, we utilized visual servoing to generate a motion trajectory while the robot is moving its hand instead of planning a motion trajectory in advance. Visual servoing determines the trajectory from the current waypoint to the next one in real time based on the image captured by a camera mounted on the robot hand.

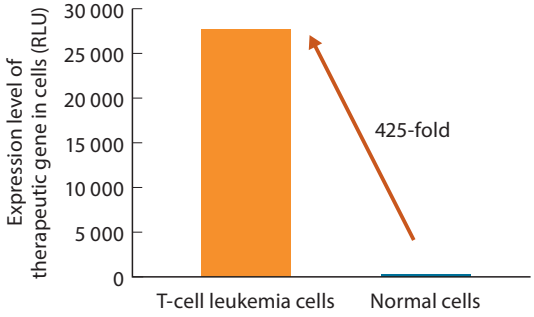
We experimented with picking typical small boxes with the new picking robot. As a result, the robot achieved the industry's top-class picking speed of 1 000 picks per hour(*).

(*) As of January 2020 (as researched by Toshiba Corporation)

1.21 Tumor-Tropic Liposome Technology for Selective Delivery of Therapeutic Genes to Tumor Cells

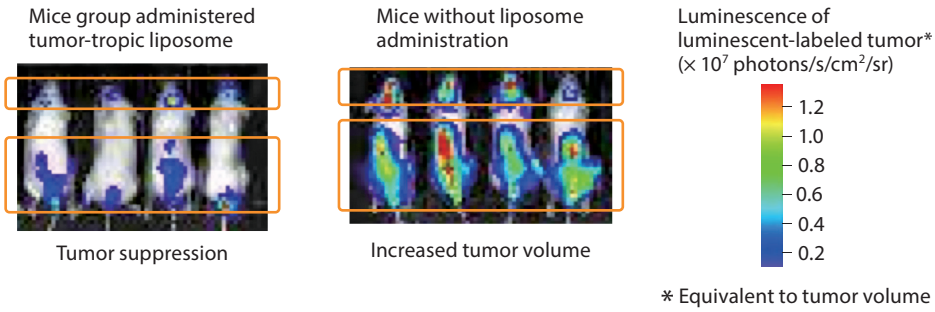


Mechanism of tumor-tropic liposome technology to selectively deliver therapeutic genes to tumor cells



RLU: relative light unit

Effect of therapeutic gene delivery using tumor-tropic liposomes



Results of administration of tumor-tropic liposomes with therapeutic gene incorporating cell-killing function to tumor-transplanted mice

The most important means of improving the efficacy of gene therapy is to maximize the efficiency of gene delivery to the target cells. Tools for selective gene delivery help to improve the efficiency of gene transfer.

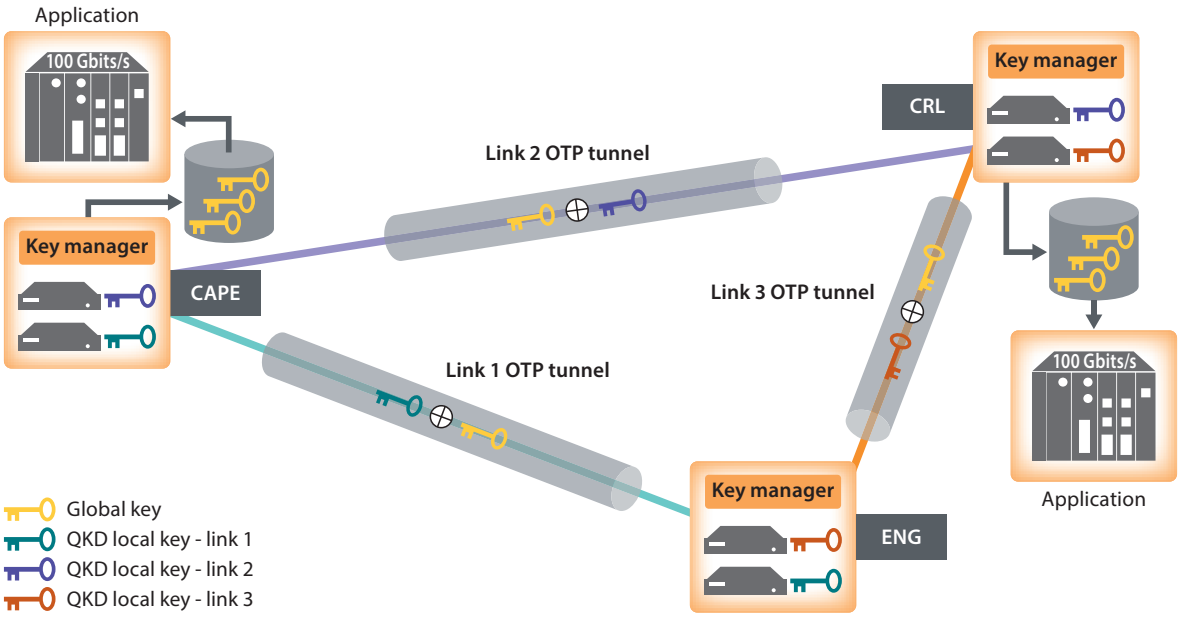
Toshiba Corporation has developed a tumor-tropic liposome as a promising tool for selectively delivering therapeutic genes to tumor cells. A liposome is a nano-sized capsule with a diameter of about 100 nm containing artificial lipids that can encapsulate therapeutic genes. Because of its high uptake ability, the liposome expresses therapeutic effects when the encapsulated therapeutic genes express in tumor cells.

Our tumor-tropic liposome can deliver therapeutic genes selectively to tumor cells because it contains biodegradable lipids that we developed using our accumulated know-how in materials technology. We applied machine learning to optimize the compositions of the lipids. Consequently, the tumor-tropic liposome targeted at T-cell leukemia cells demonstrated a 425-fold increase in therapeutic gene expression inside the leukemia cells compared with normal T-cells. Moreover, collaborative research with Shinshu University has shown that a tumor-tropic liposome with therapeutic genes having a cell-killing function successfully suppressed tumor cell growth in mice with transplanted human tumor cells(*).

We will apply this liposome technology to diagnosis, regenerative medicine, and other medical fields.

(*) Toshiba Corporation and Shinshu University presented this technology at the 2020 Annual Meeting of the American Society for Gene & Cell Therapy (ASGCT 2020) on May 12, 2020.

1.22 Cambridge Quantum Network



Overview of Cambridge quantum network composed of three single-fiber high-speed QKD links

Metropolitan fiber communication networks underpin the fabric of society. Future-proofing these networks by means of quantum key distribution (QKD) is an attractive way to fight the emerging threat of data theft. Furthermore, any integration of QKD into these networks should be as seamless as possible. This typically involves QKD operating over network fibers "lit" with existing classical data traffic.

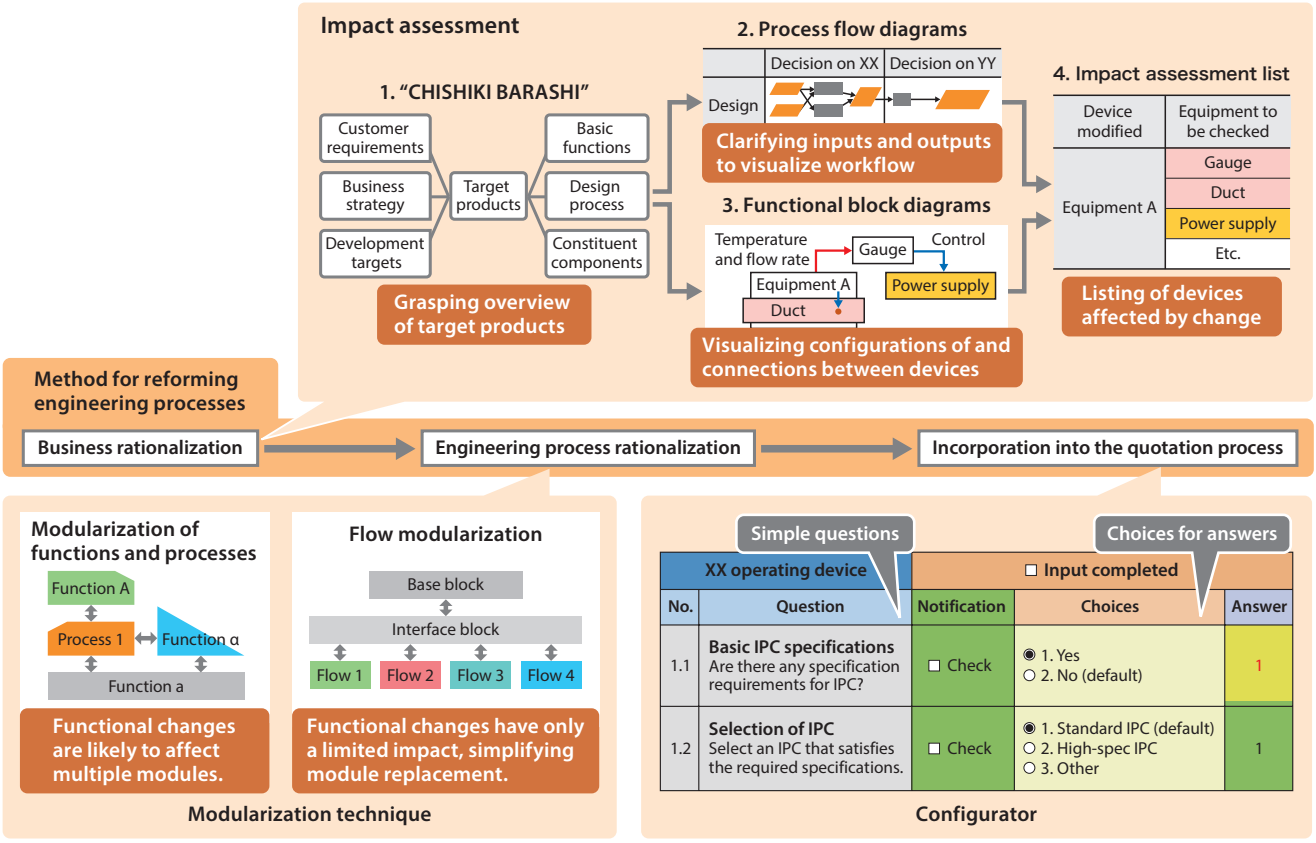
The Cambridge Research Laboratory (CRL) of Toshiba Europe Ltd. has built a quantum network in the city of Cambridge in the United Kingdom using its prototype QKD systems operating at a frequency of 1 GHz. The quantum network is composed of three single-fiber high-speed QKD links, forming a triangular quantum network. Each link spans a short metropolitan distance of 5 to 11 km between three sites: the Centre for Advanced Photonics and Electronics (CAPE) at the University of Cambridge's Cavendish Laboratory site, the university's Engineering Department (ENG) in the south of the city, and CRL located in the northeast of the city. Long-term operation of the QKD (quantum) layer in the Cambridge quantum network has been realized. The three links distilled, on average, 120 Tbits (T: tera = 10^{12}) of secure key material over 1.6 years at an average secure key rate of 2.5 Mbit/s, including stoppages.

A key management layer with an application programming interface (API) was developed and deployed in the Cambridge quantum network. The key management layer collects QKD keys from the quantum layer and uses these keys for one-time-pad (OTP)(*) encryption tunnels between the three sites. Quantum-encrypted "global" keys can then be relayed around the network for use by third-party applications employing a unique "key pull" mechanism. In this way, applications can request keys through the API using an "on-demand" technique.

A key relay has been successfully demonstrated in the Cambridge quantum network for keys supplied to a 100 Gbit/s encrypted application link operating over the same fiber link as QKD (CAPE–CRL). By forcing this link to stop delivering keys, the network reacted favorably and rerouted the keys via a third site (ENG) using the other two QKD links. No service interruption was observed on the application side, indicating that the key rerouting had been executed successfully.

(*) A common key cryptosystem that uses a single-use encryption key having the same length as the plaintext

1.23 Method for Reforming Engineering Processes to Improve Basic Earning Power



IPC: industrial PC (i.e., industrial computer)

Establishment of method for reforming engineering processes

In order to improve basic earning power, the manufacturing industry has conventionally reduced engineering costs through the standardization and commonization of processes and parts.

Toshiba Corporation has developed a method for reforming engineering processes to improve the basic earning power of build-to-order and other types of high-mix low-volume production. The newly developed method makes it possible to address variable design factors while satisfying diverse customer requirements.

This method consists of three stages: (1) business rationalization, (2) engineering process rationalization, and (3) incorporation into the quotation process.

(1) Business rationalization

We have developed a new technique to evaluate the possible impacts on business (e.g., parts costs and design work-hours) caused by changes to product strategies, specifications, and designs. The new technique uses our proprietary "CHISHIKI BARASHI" methodology to visually represent business-related information as process flow and functional block diagrams in order to evaluate the fitness and rationality of an entire business. This technique

clarifies the impact of specification changes on an overall system. It is therefore effective in reducing design iterations for build-to-order products and in evaluating the importance of the elements being developed under R&D programs.

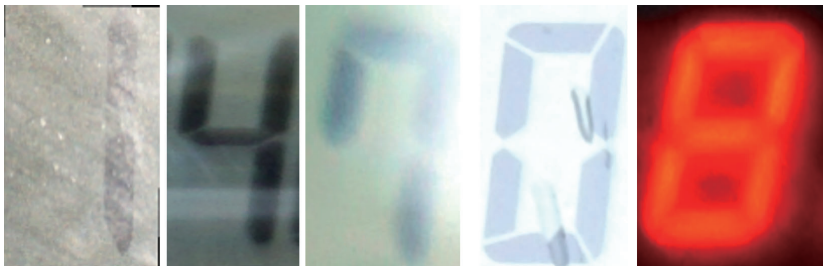
(2) Engineering process rationalization

In addition to the conventional procedure used for combining modular functions and processes, we have developed a new technique to modularize the flow of functions and processes. Applicable to both hardware and software, this flow modularization technique helps to reduce the scope of impacts caused by the addition or replacement of functions. It therefore simplifies product customization, even in the case of products having a complex combination of many functions. For example, we were able to reduce the number of work-hours required for the design of an embedded software product by 80%.

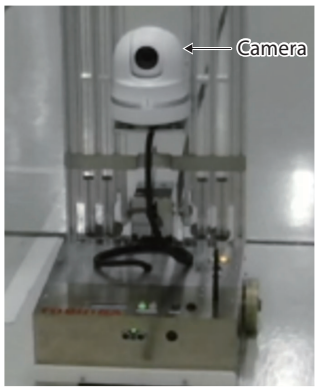
(3) Incorporation into the quotation process

At an early stage of development, only a rough specification is generally available. We have developed a function for automatically setting yet-to-be-determined specifications, taking prohibitions into consideration. We have also developed a spreadsheet-like configurator that incorporates modular quotation procedures. This configurator generates a quotation based on the answers to a few simple questions. It delivers a 30% reduction in the time required to create a quotation for infrastructure system products.

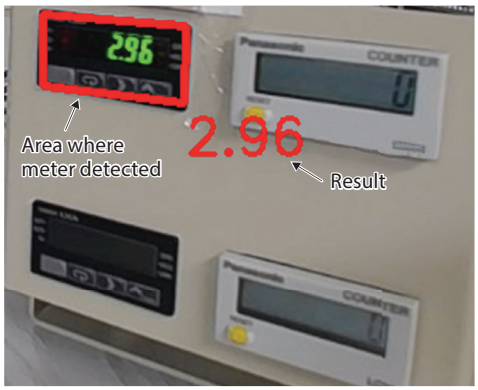
1.24 High-Precision Meter Recognition Using Deep Learning



Examples of difficult-to-read numerical images



AGV equipped with meter reading technology



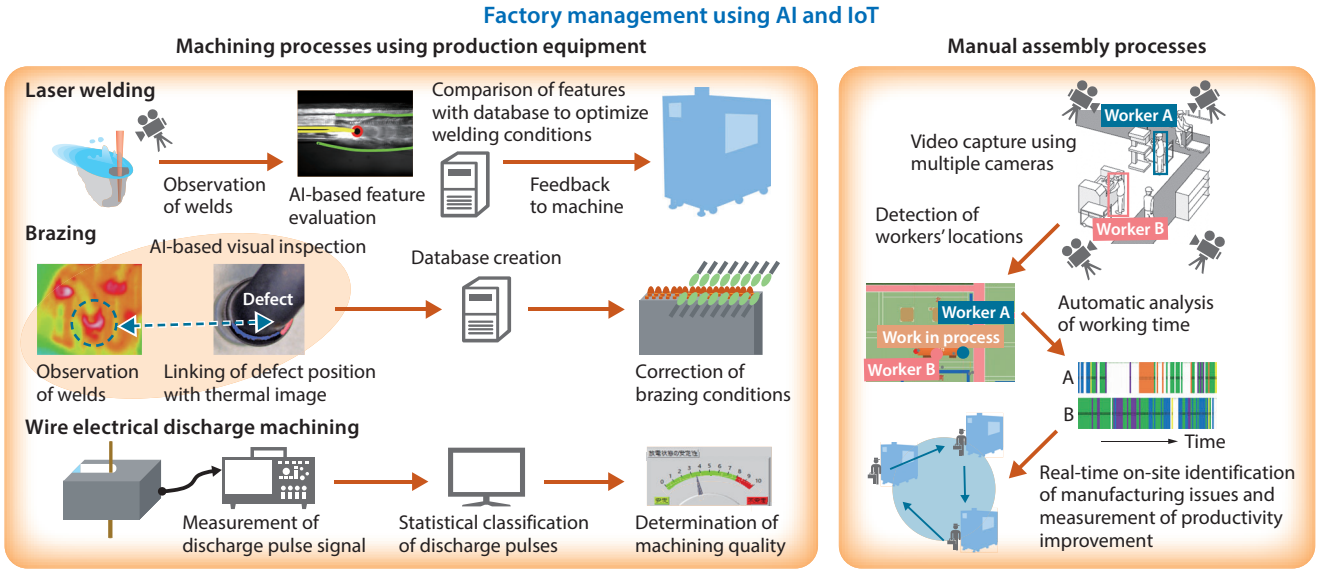
Detection of digital meters and reading of numerical values

Infrastructure and energy facilities have many meters that are not connected to any network, making it necessary for human workers to make the rounds to check on these meters and create reports.

In order to save labor costs, Toshiba Corporation has developed a meter recognition technology to automatically detect meters from images captured with a camera, read the meter values, and convert them to electronic data. Conventionally, image processing techniques such as binarization and delineation have been used to recognize numerical values. With these techniques, however, it has been difficult to improve the recognition accuracy when meter images have low contrast, blur, or a reflection of ambient light.

In this development project, we applied a six-layer deep-learning technique called convolutional neural networks (CNNs) to the numeric recognition algorithm, increasing the recognition accuracy from 56.8% to 99.7%. In addition, we optimized the software to parallelize image acquisition, meter position search, and numeric recognition and utilized an inference accelerator on a single-board computer. As a result, the run-time required from image capture to recognition result output has been reduced from 130 ms to 33 ms. The newly developed technique realizes high-accuracy meter reading using images taken by human workers, automatic guided vehicles (AGVs), drones, and other moving vehicles.

1.25 Automated Manufacturing Technology Using AI and IoT



Automation of machining processes using production equipment and manual assembly processes by means of AI and IoT

Many conventional manufacturing processes require experienced workers who have been in short supply in recent years, making it necessary to assign less experienced workers to these processes.

Under these circumstances, Toshiba Corporation has developed an automated manufacturing technology by quantifying tacit "black-box" skills using AI and the IoT.

For example, laser welding conditions depend on the shape of the workpiece and ambient environmental conditions. We have developed a control system that corrects the welding conditions autonomously. This system automatically extracts weld features from real-time images and compares them with a pre-prepared welding condition database in order to make necessary corrections.

We have also developed a system for optimizing brazing conditions by matching changes in the brazing temperature with the results of AI-based visual inspection.

For wire electrical discharge machining, we have developed a system that measures the discharge current and voltage signals at the working point and uses a statistical technique for the classification of discharge pulses in order to quantify the machining quality.

In the case of manual assembly processes, we have developed an AI-based tool to automatically detect the locations of workers from video images in order to analyze their traffic flow as well as their working and waiting times. This tool automatically visualizes their actual productivity and workloads, making it possible to resolve issues in real time without relying on experienced engineers.

These systems mimic the "black-box" skills of experienced workers to support less experienced workers.

1.26 Autonomous Mobile Robot to Save Labor Required for Logistics and Manufacturing

Autonomous mobile robot equipped with laser distance sensor and Mecanum wheels

Toshiba Corporation has developed an autonomous mobile transport robot for logistics and manufacturing sites and commenced its application to manufacturing processes within the Toshiba Group.

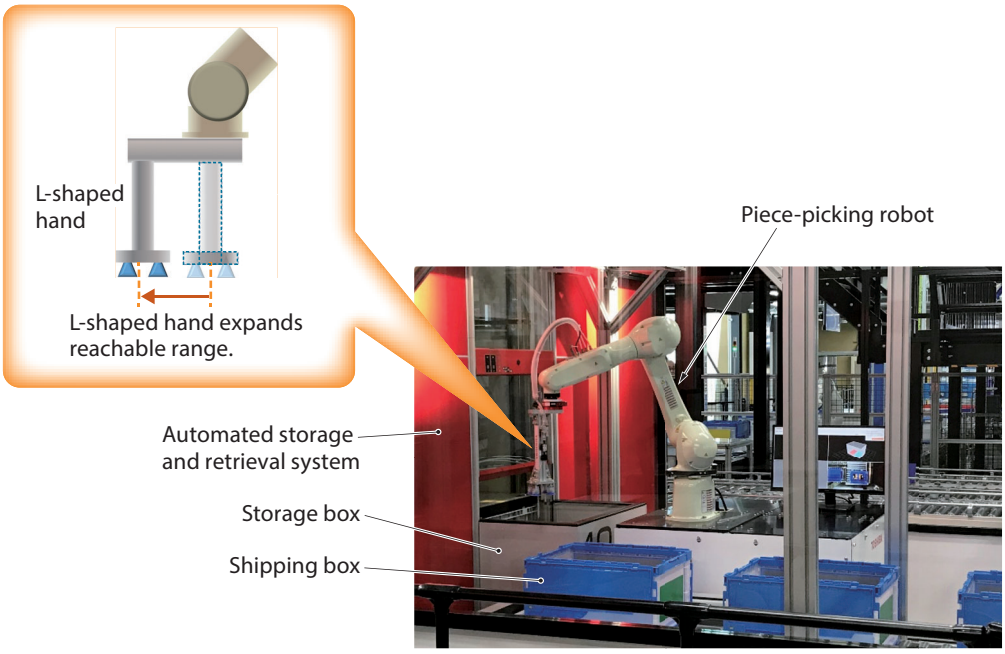
Many conventional mobile robots move on two wheels along a guide tape on the floor. Because of their relatively large turning radius, two-wheeled robots are not ideal in terms of travel time. They also require that the rotation and travel ranges be taken into consideration when attaching the guide tape. In addition, the guide tape must be reattached when it is necessary to change the robot's route.

Our newly developed mobile robot is equipped with a laser distance sensor to measure the surrounding environment so as to move autonomously while recognizing its own position, and is capable of moving in any direction using Mecanum wheels(*). We have combined this mobile robot with a robot arm equipped with an inspection probe to automate the transport and inspection processes, contributing to the improvement of productivity and safety. Furthermore, the automatic collection of inspection data results in improved traceability of the manufacturing process.

Our next step is to enable this mobile robot to communicate with a manufacturing execution system (MES) so as to visualize its movement and work history and thereby further improve manufacturing efficiency.

(*) Wheels with rollers attached to the whole circumference of their rim at an angle of 45°

1.27 Piece-Picking Robot Contributing to Full Automation of Distribution Centers



Piece-picking robot for automatically shipping products in conjunction with automated storage and retrieval system

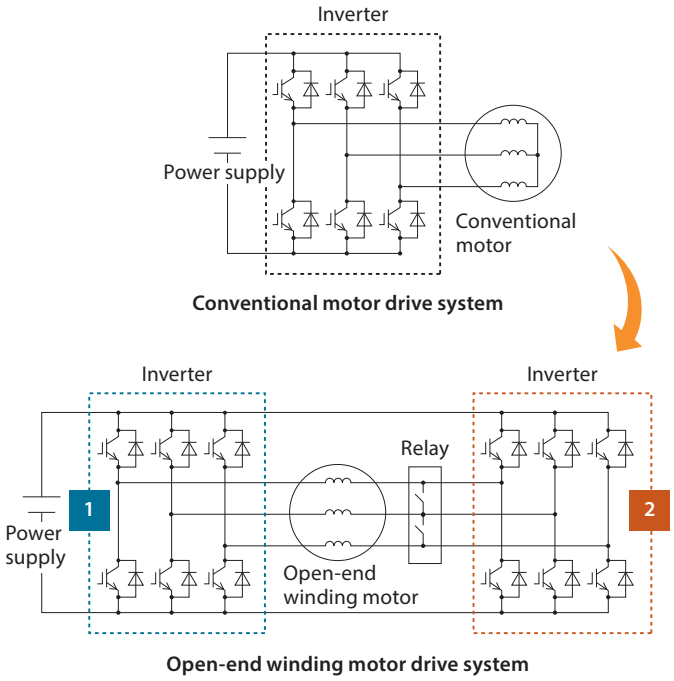
In response to the growing need to save labor at distribution centers, Toshiba Corporation has developed an automatic piece-picking robot and delivered it to a major logistics facility operator for demonstration purposes as a key component of a fully automatic logistics system.

To automate picking, a robot is required to have the capability to load and unload items anywhere in a storage or shipping box without knocking them or the box. In addition, a warehouse has constraints on the space available for the installation of a robot. To meet these requirements, we have developed (1) an L-shaped hand that can extend its tip farther than the conventional straight hand and (2) a high-speed planning technique for calculating the gripping position that will not cause a collision. As a result, our robot is small enough for easy installation and can access items at the corner of a box at high speed. It has achieved a picking rate of 500 picks per hour(*), which is fast enough to be connected to an automatic warehouse.

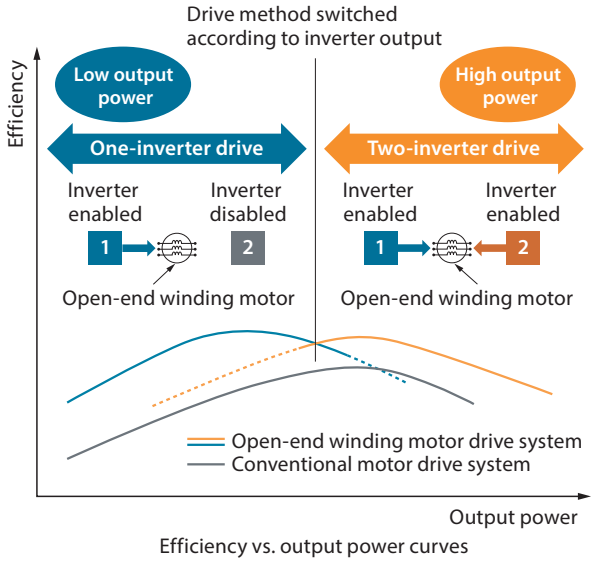
We will continue to develop technologies to further automate and speed up picking operations so as to contribute to labor-saving in the field of logistics.

(*) Throughput depends on the stacking and item conditions.

1.28 Open-End Winding Motor Drive System to Achieve High Output Power and Efficiency



Configuration of open-end winding motor drive system using two inverters



High output and high efficiency achieved by switching between one-inverter drive and two-inverter drive according to usage conditions

A conventional motor is designed to operate over a wide range of output power and provide high efficiency at medium output power. However, increasing the output power causes the inverter circuit current to increase, which in turn causes the motor efficiency to decrease.

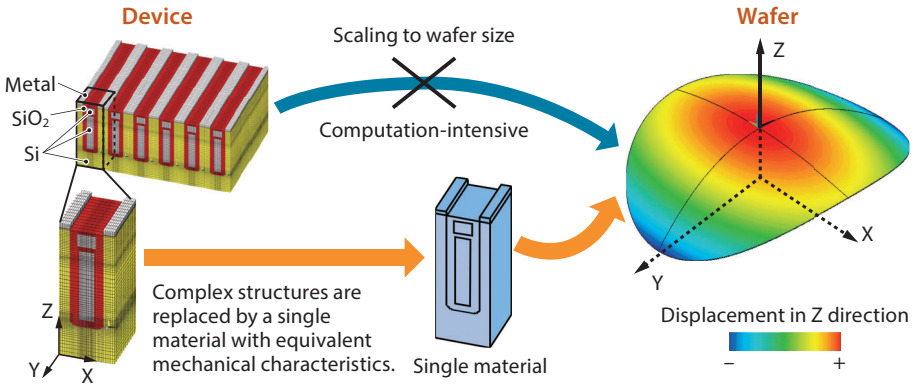
To solve this problem, Toshiba Corporation has developed an open-end winding motor drive system in which a motor with open-end windings is connected to two inverter circuits and selectively driven by one or both inverter circuits according to the inverter output power conditions.

At low output power, the new motor drive system is driven by one inverter, with the relay closed, to achieve high efficiency. At high output power, it uses two inverters, with the relay opened, to deliver about 1.7 times greater voltage to the motor than the conventional system, reducing the circuit current by about 40%. As a result, our new motor drive system achieves higher output power and efficiency than conventional systems.

We have applied the new motor drive system to business-use air conditioners for the first time in the world(*). Our next step is to expand its application to other social infrastructure products.

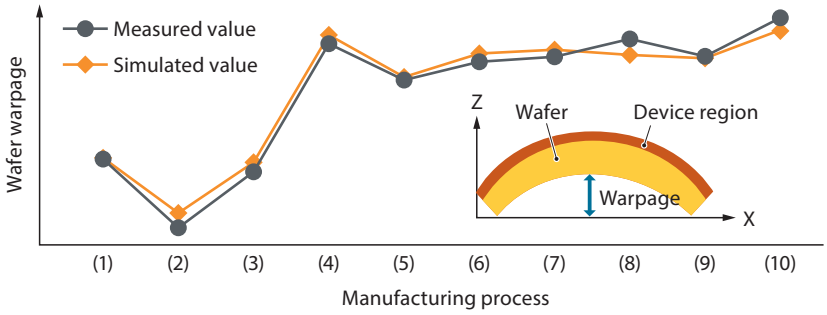
(*) As of December 2019 for variable-refrigerant-flow air-conditioning systems (as researched by Toshiba Corporation)

1.29 Technique for Predicting Wafer Warpage in Silicon Power Devices to Improve Efficiency of Manufacturing Process Development



SiO_2: silicon dioxide

Prediction of Si power device wafer warpage using multiscale stress simulation



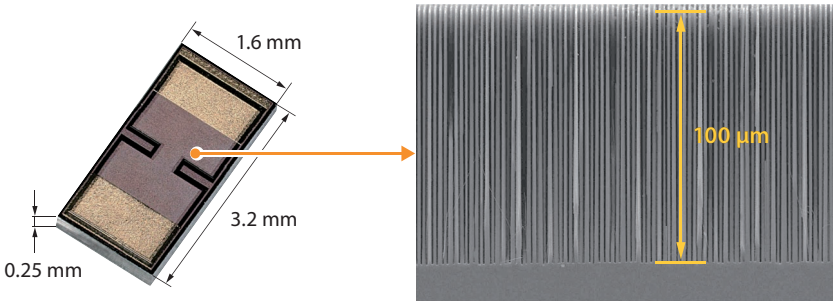
Comparison of measured and simulated values of wafer warpage in each manufacturing process

In recent years, vertical silicon (Si) power devices with very low on-resistance have been widely developed. However, the Si wafers on which vertical Si power devices are fabricated tend to warp during manufacturing, causing failures of wafer conveying systems. To avoid these failures, it is effective to predict wafer warpage through stress simulation. However, wafer warpage simulation is impracticably computation-intensive because it requires a simulation model consisting of many micrometer-scale devices.

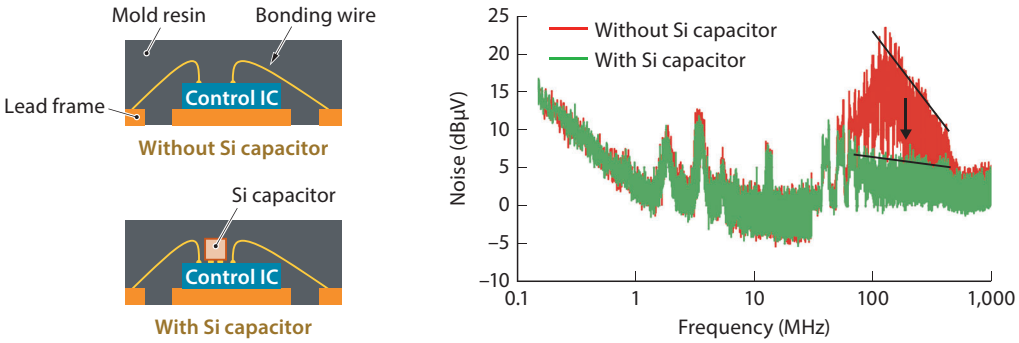
To solve this issue, Toshiba Corporation applied a homogenization method to the conventional method of stress simulation, replacing complex structures and materials in the simulation model with a single material having equivalent mechanical characteristics. As a result, we succeeded in reducing the simulation workload by a factor of several hundred million without compromising accuracy. The newly developed simulation technique can precisely predict the occurrence of wafer warpage variations in each manufacturing process.

The new simulation technique makes it possible to realize efficient process integration, shorten the development period, and optimize the device design. In the future, we will use this technique for the design and development of next-generation Si power devices.

1.30 Technology to Fabricate High-Capacity Silicon Capacitors Using New Etching Technique



Prototype Si capacitor chip fabricated using MacEtch process



Electromagnetic noise suppression achieved by prototype chip used as decoupling capacitor

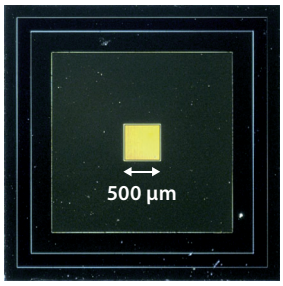
For automotive control integrated circuits (ICs), it is important to reduce the electromagnetic noise generated. Toshiba Corporation has developed a technology for manufacturing high-capacity silicon (Si) capacitors at low cost and demonstrated that incorporating an Si decoupling capacitor into an IC helps to significantly reduce the electromagnetic noise of the IC.

Si capacitors can be made thinner than multilayer ceramic capacitors and have the advantage that their capacitance is less dependent on temperature. Furthermore, an Si chip can be mounted directly on the IC chip because they have the same coefficient of thermal expansion.

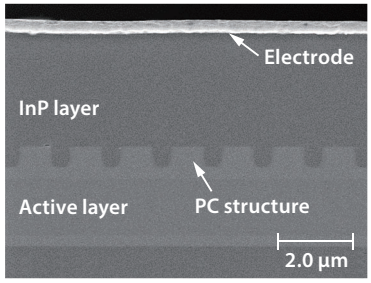
Generally, a trench is formed on the Si substrate, and a dielectric film is formed on the surface to form a capacitor. However, increasing the depth of the trench to increase the capacity causes the manufacturing cost to increase. To solve this problem, we have developed a method of metal-assisted chemical etching (MacEtch), a type of anisotropic wet etching using a metal catalyst, to form a trench with an aspect ratio of 100 or more on the Si substrate at low cost. As a result, we have achieved a capacitance density of more than 200 nF/mm^2.

It is expected that this technology will help to improve the electrical characteristics of various automotive control ICs.

1.31 Mid-Infrared Semiconductor Laser for High-Sensitivity Remote Gas Sensing

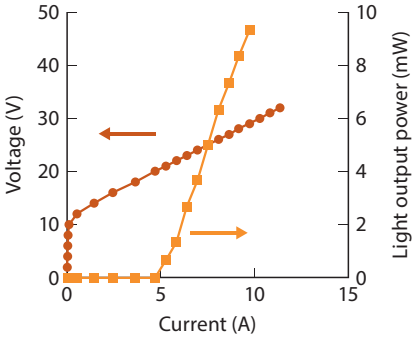


Prototype surface-emitting quantum cascade laser (QCL) using photonic crystals (PCs)

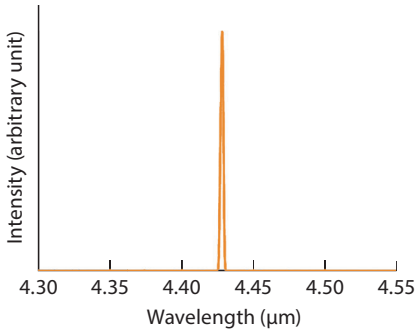


InP: indium phosphide

Scanning electron microscope (SEM) image of fabricated PCs



Current-voltage and current-light output characteristics



Lasing spectrum

Current-voltage-light output characteristics and lasing spectrum

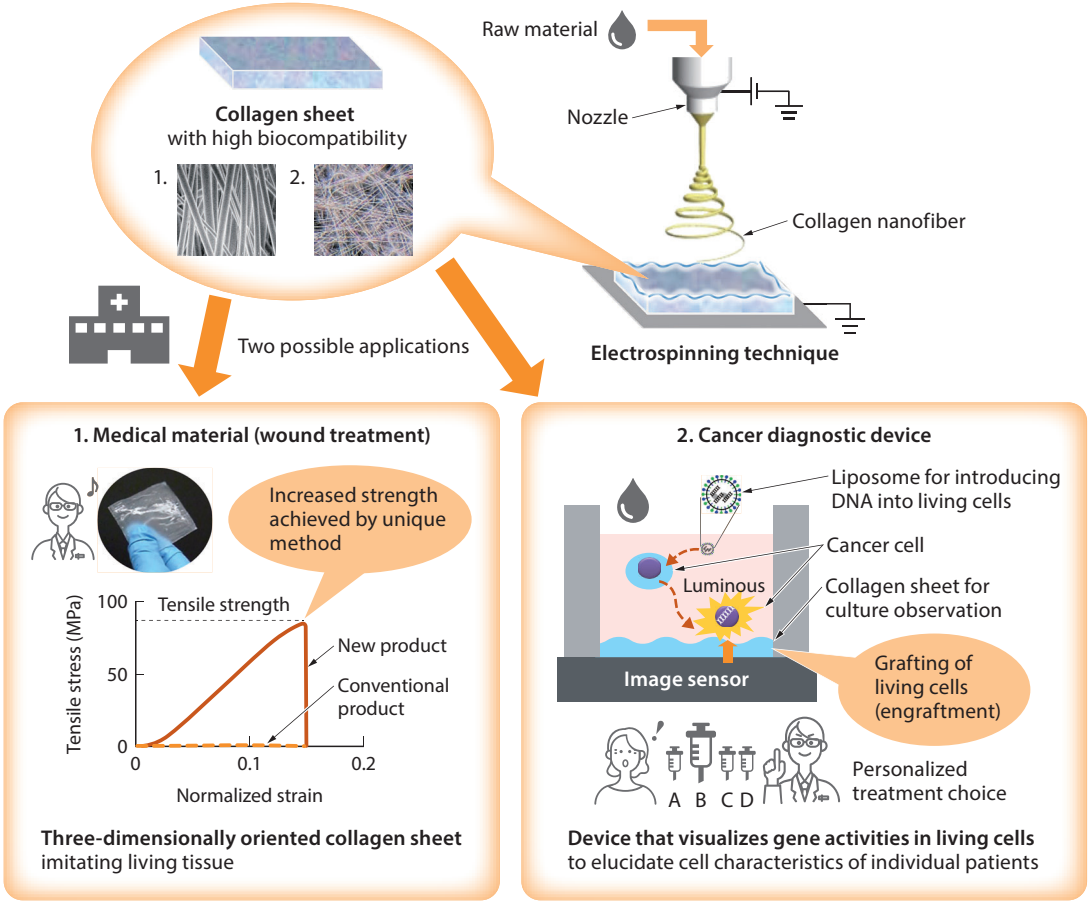
The quantum cascade laser (QCL) is a type of mid- to far-infrared semiconductor laser that is expected to be used as a light source for high-sensitivity remote gas sensing and medical applications.

Toshiba Corporation is developing a surface-emitting QCL with photonic crystals (PCs) that combines high output power and high beam quality and provides excellent manufacturability. We have now designed and fabricated a surface-emitting QCL using atomic-order-controlled semiconductor epitaxial growth technology, high-precision lithography, and dry-etching technology. In an evaluation of this QCL, we achieved pulsed lasing operation in the 4 µm wavelength range for the first time in the world(*). The surface emission had a beam divergence angle of less than 2°. We will optimize the PC structure to further improve both the output power and the beam quality.

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

(*) As of March 2020 for a QCL with a 4 µm wavelength using PCs (as researched by Toshiba Corporation)

1.32 Collagen Sheets for Precision Medicine Fabricated Using Nanofiber Technique



Two types of collagen nanofiber sheets for precision medicine manufactured using electrospinning technique

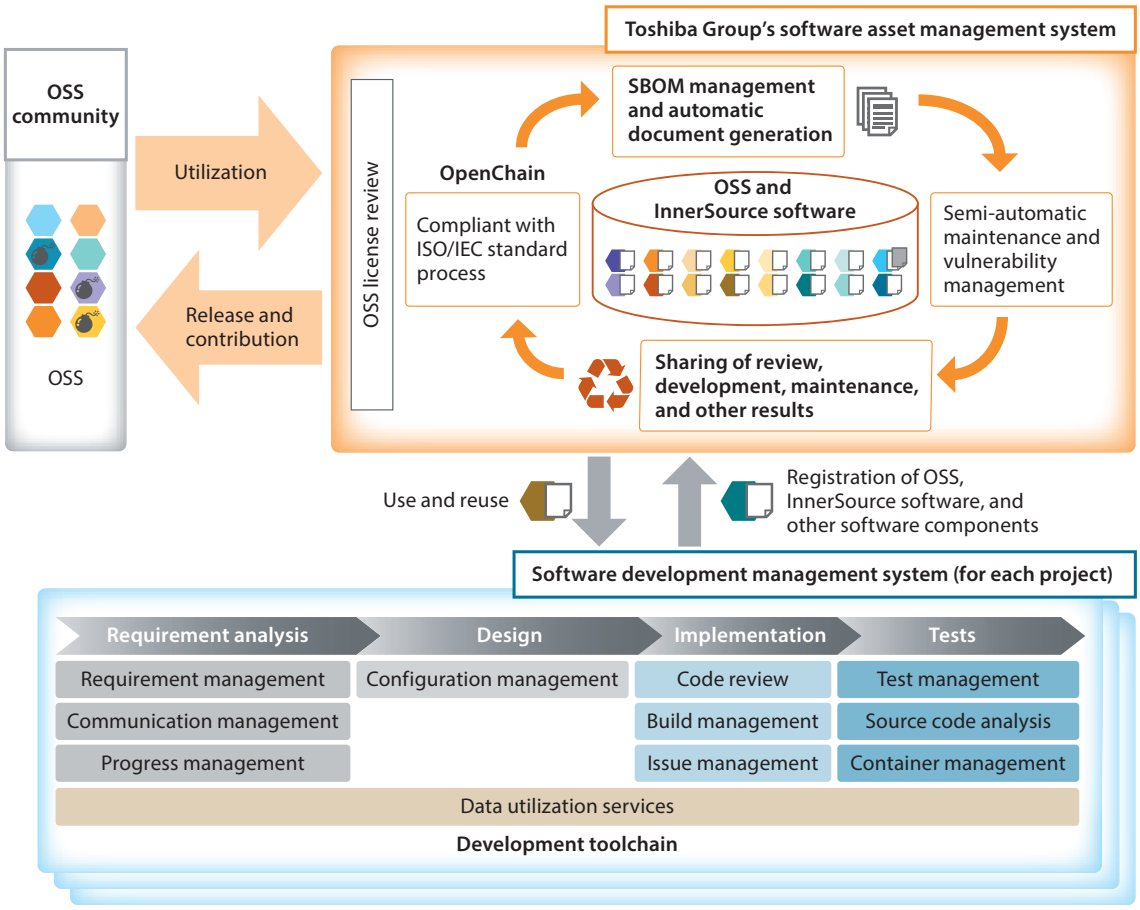
Toshiba Corporation has developed two types of collagen nanofiber sheets for precision medicine: (1) a high-strength, easy-to-handle sheet for wound treatment and regenerative medicine and (2) a sheet for cancer diagnostic devices that visualize the gene activities in living cells. Electrospinning is utilized to spin collagen into nanofiber at room temperature.

For the high-strength collagen sheet, we employ a unique adhesion treatment technique using liquid capillary force in order to replicate the three-dimensionally oriented structure of living tissues, thereby increasing the tensile strength to about 80 MPa. This allows the high-strength collagen sheet to be easily grasped with tweezers or a scalpel. In joint research with Tokyo Medical and Dental University, we have confirmed that it is rapidly absorbed through rat skin.

The other type of collagen sheet facilitates early cancer diagnosis. We have succeeded in observing living breast cancer cells with an engraftment rate of 80% or more by forming a transparent collagen sheet with high cell affinity on the surface of an image sensor.

We will continue with basic verification to achieve practical use in collaboration with the internal and external parties concerned.

1.33 Collaborative Software Development Platform to Facilitate Consistent Management and Reuse of Software Components



SBOM: software bill of materials

Concept of Toshiba Group's collaborative software development platform

Toshiba Corporation has developed a collaborative software development platform to improve the efficiency of software development in the Toshiba Group. This platform consists of the following two systems:

(1) Software asset management system

The software asset management system supports the introduction of InnerSource, an open source-like culture within organizations for collaborative software development. This system also serves as a catalog of software components. It supports the analysis and management of open source software (OSS) components to comply with the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 5230:2020 "Information technology — OpenChain Specification" international standard(*) for open source compliance process management.

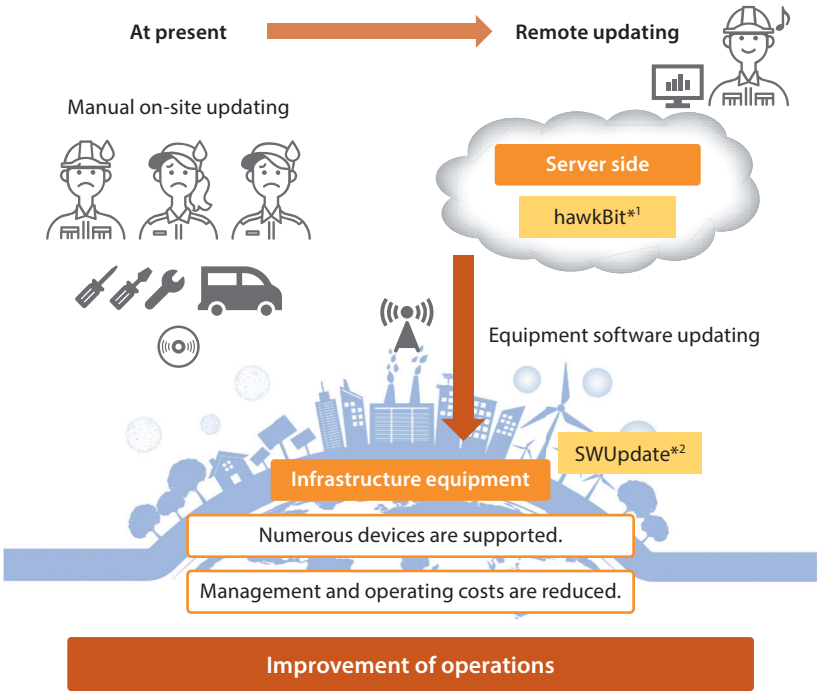
(2) Software development management system

The software development management system supports the implementation of DevOps, a set of practices that combine software development and operations. This system facilitates both the waterfall and agile software development methodologies as well as deliverables management.

The newly developed software development platform is expected to improve the efficiency of the open source compliance process and the reusability of software components.

(*) An open source project aiming to achieve consistent OSS compliance across the supply chain

1.34 Remote Software Updating for Linux®-Based IoT Systems



*1: An OSS installed on a server to register a large number of devices and manage software updating for them

*2: An OSS installed on embedded devices to authenticate, download, install, and test updates

Improvement of on-site work by updating remote software of infrastructure equipment

IoT systems require software updating to fix security vulnerabilities and add new enhancements. To meet these needs, Toshiba Corporation has developed a remote software updating technology for Linux®-based IoT systems.

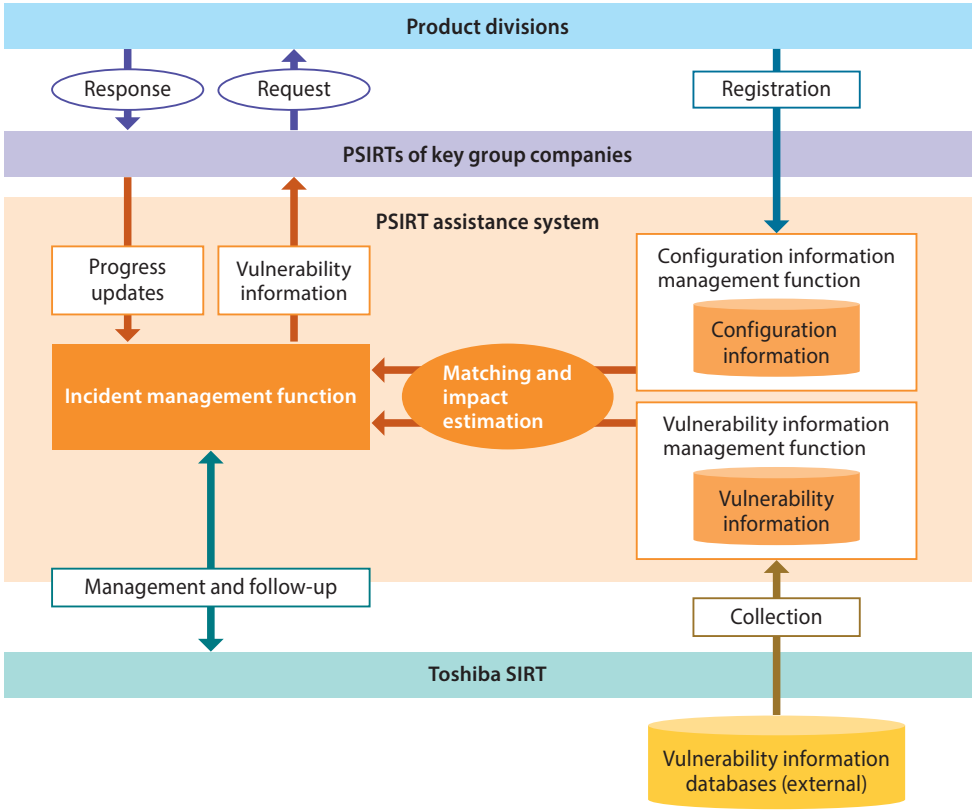
In the case of an IoT system requiring remote software updating, the software running on an embedded device must have the functions necessary to detect software update requests; download, authenticate, install and test updates; and recover from failed updating. In contrast, the software running on the server must have the functions necessary to manage a large number of embedded devices, distribute software updates to them, and track their software updating status.

We expect that the newly developed technology will save the labor required to perform software updating that was previously handled by field workers, reduce the operating costs of IoT systems for social infrastructure, and enable software updating in a timely manner.

We have implemented this technology using open source software (OSS) and created a proof of concept. Next, we plan to apply this technology to remote monitoring systems for social infrastructure used in the Toshiba Group.

Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

1.35 PSIRT Assistance System to Enhance Product Security Response



SIRT: Security Incident Response Team

Overview of automated processes for labor saving to address vulnerabilities in products achieved by PSIRT assistance system

The Toshiba Group places high importance on prompt responses to vulnerability information in order to reduce business risk for its customers. To cope with ever-increasing product vulnerabilities, Toshiba Corporation has developed a Product Security Incident Response Team (PSIRT) assistance system for prompt and reliable handling of vulnerability information.

The PSIRT assistance system automates and reduces the burden of vulnerability handling. The product divisions of the Toshiba Group register the configurations of their products with the PSIRT assistance system. Whenever any vulnerabilities are published on the JVN iPedia or other vulnerability information databases, the PSIRT assistance system automatically determines whether they might affect any of the registered products and notifies the people responsible for the relevant products. They are requested to cooperate with the members of the PSIRT to evaluate possible impacts of the vulnerabilities, take countermeasures, and announce them to the public according to a predefined flow. The PSIRT assistance system is also utilized for the unified management of response status information, which can be viewed from the system's dashboard.