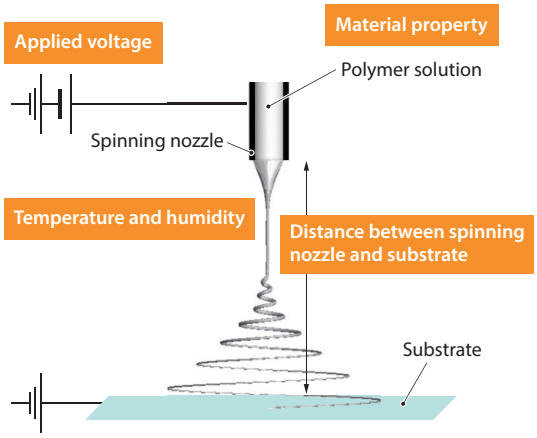
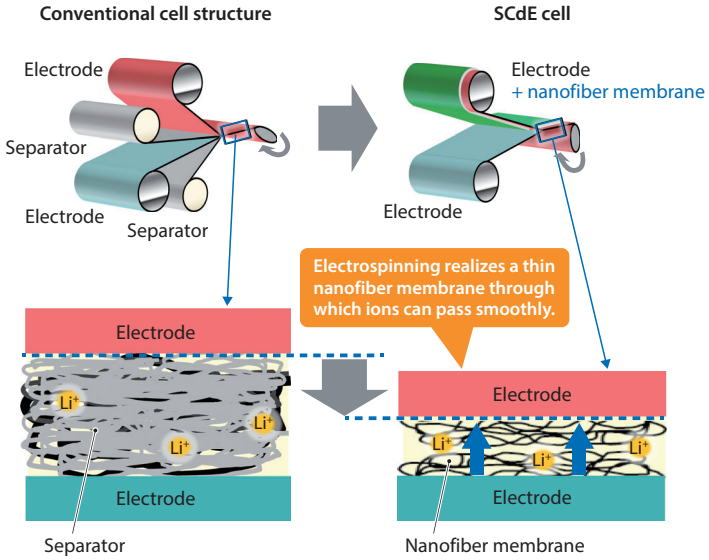
Research and Development

SCiB™ Battery with New Structure Applying Nanofiber Membranes Produced by Electrospinning



Control parameters of electrospinning for nanofiber formation



The nanofiber membrane is fabricated directly on the electrode.
⇒ Capacity and input/output power are increased while reducing costs.

Li^+: lithium ion

Newly developed skin-coated electrode (SCdE) as alternative to separator in cell

Nanofiber fabrication techniques are employed for the molding of various materials. Because of their large specific surface area, nanofibers are utilized in catalysts, filters, and biomaterials. Electrospinning is a nanofiber forming technique in which a high voltage is applied to a spinning nozzle filled with a polymer solution to draw out polymer nanofibers. This technique makes it possible to fabricate nanofiber membranes that can be used to create functional materials such as insulators, heat-resistant materials, and biomaterials. Due to the unique functions of nanofiber membranes fabricated by electrospinning, research and development is being actively undertaken on them in various fields.

Toshiba Corporation has now established a high-speed nanofiber membrane production technology and applied the fabricated nanofiber membranes to the development of an SCiB™ rechargeable battery with a new structure, eliminating the need for free-standing separators between the anode and cathode.

We conducted extensive research encompassing fields from the mechanism of nanofiber fabrication by electrospinning through to mass production technology. As a result of these efforts, we developed a skin-coated electrode (SCdE) by optimizing various control factors including the applied voltage, material properties, temperature, humidity, feed rate, and spinning nozzle-to-substrate distance.

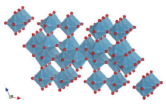
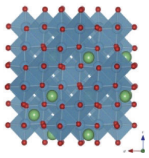
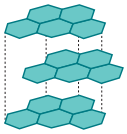
The SCdE is a novel electrode covered with an extremely thin resin nanofiber membrane. Using the SCdE, we have realized a separator-free battery design with a minimal distance between the anode and cathode. The use of the SCdE not only improves the input/output power of the SCiB™ battery but also increases its capacity per volume. In the case of the high-output-power 10 Ah SCiB™ battery, the SCdE helps to boost the output power from 1 800 W to 2 200 W. Furthermore, the application of our electrode coating technique to the SCdE makes it possible to reduce the internal resistance of the battery by approximately 40% compared with that of the conventional SCiB™. The increase in input/output power will promote the utilization of SCiB™ batteries in low-temperature environments, accelerating the replacement of lead-acid batteries with the SCiB™. The SCiB™ battery equipped with the SCdE achieves an increase in energy density from 2.9 Ah to 3.8 Ah while maintaining the same input/output power with the same can size.

Our tests also showed that the SCiB™ battery with the new structure maintains more than 95% of its capacity after 8 000 charge-discharge cycles. The new SCiB™ battery thus provides an advantage in terms of long life in addition to high input/output power and high energy density.

Our next step is to achieve practical application of the new SCiB™ battery and expand its application to vehicles, railway systems, and stationary devices.

Next-Generation SCiB™ Lithium-Ion Rechargeable Battery with High Energy Density Using New Oxide-Based Anode

Comparison of characteristics of conventional graphite, LTO, and TNO anodes

Anode material	$TiNb_2O_7$ (TNO)	LTO	Graphite
Crystal structure	Monoclinic 	Spinel 	Hexagonal 
Redox couples	Ti^{4+}/Ti^{3+} Nb^{5+}/Nb^{3+}	Ti^{4+}/Ti^{3+}	C_6/C_6^-
True density (g/cm^3)	4.34	3.41	2.25
Per-weight capacity(*1) (mAh/g)	387	170	372
Volumetric capacity(*1) (mAh/cm^3)	1 680	580	837
Electrode potential(*2) (V vs. Li)	1.6	1.55	0.2

Ti: titanium Nb: niobium C: carbon Li: lithium

(*1) Theoretical value per unit cell
(*2) Potential referenced to an equilibrium potential of 0 V for a lithium-metal electrode

Prototype battery equipped with TNO anode

To enhance the convenience of electric vehicles (EVs), both expansion of the cruising range per charge and shortening of the charging time are required.

Toshiba Corporation has developed and released a lineup of SCiB™ lithium-ion rechargeable batteries offering high-speed charging, high safety, and a long lifetime.

Since 2011, we have been developing a new battery using a titanium-niobium oxide (TNO: $TiNb_2O_7$) anode that has double the volumetric capacity of the graphite-based anodes generally used for lithium-ion batteries. The element niobium (Nb) in this material makes possible a two-electron reaction at the same electrode potential as lithium-titanium oxide (LTO) during the lithium-ion insertion process and is characterized by high true density. Compared with a graphite anode, TNO has an equivalent per-weight capacity and double the volumetric capacity, and is thus expected to be applied to EVs.

We have now developed a synthesis method to improve the crystallinity of the TNO particles of a TNO anode and achieved a real capacity close to the theoretical value. Experiments on a prototype battery with a capacity of 49 Ah using this TNO anode have confirmed that it offers ultra-high-speed charging of up to 90% of the nominal capacity in six minutes and can maintain 90% of the initial capacity after 5 000 charge/discharge cycles. This higher energy density battery makes it possible to expand the cruising range of compact EVs to 320 km(*) per charge with a charging time of only six minutes, and is expected to improve the usability of EVs.

(*) Estimated cruising range based on JC08 mode for a compact EV equipped with a 32 kWh battery pack

SiC Trench-Gate MOSFET Realizing Reduction in Electric Power Loss

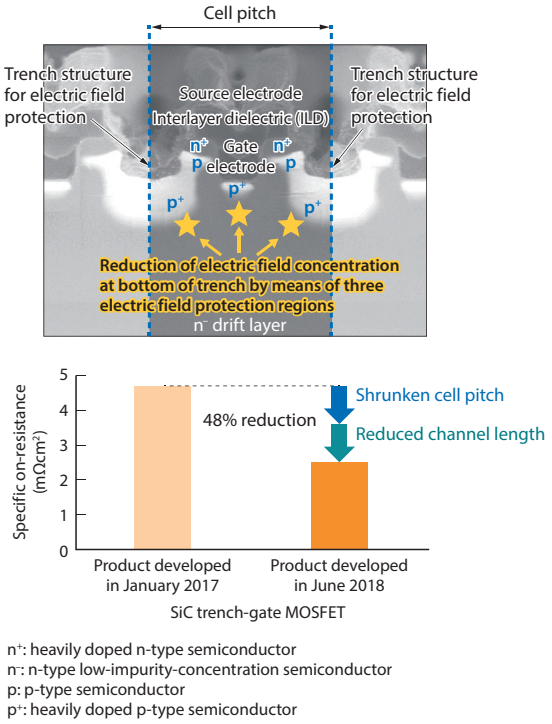
Silicon carbide (SiC) power devices help to increase the efficiency and reduce the size of power converter systems for railway vehicles, EVs, and other applications. To address these needs, Toshiba Corporation has developed an SiC trench-gate metal-oxide-semiconductor field-effect transistor (MOSFET) switching device with the industry's lowest-class on-resistance(*).

The forming of a trench gate on the wafer surface of an SiC MOSFET can be expected to reduce its on-resistance compared with a conventional planar-gate MOSFET. However, there is concern that the large electric field concentration produced at the bottom of the trench might reduce device reliability. To solve this problem, we have developed a unique device structure with three self-aligned electric field protection regions per unit cell around the trench.

The newly developed SiC trench-gate MOSFET has achieved a specific on-resistance of 2.5 mΩcm^2, 48% lower than that of a conventional MOSFET, and consequently a reduction in electric power loss, owing to the shrinkage of the cell pitch and reduction of the channel length (i.e., the electron path acting as a switch).

Part of this work was implemented under a joint research project of Tsukuba Power Electronics Constellations (TPEC).

(*) As of December 2018 for 1.2 kV-class MOSFETs (as researched by Toshiba Corporation)



n+: heavily doped n-type semiconductor
n-: n-type low-impurity-concentration semiconductor
p: p-type semiconductor
p+: heavily doped p-type semiconductor

Cross-sectional structure and reduction in specific on-resistance of newly developed SiC trench-gate MOSFET

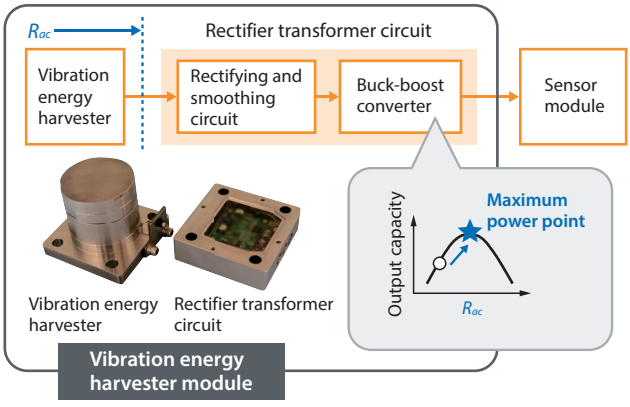
Electromagnetic Vibration Energy Harvester Module for Railway Vehicle Monitoring

Safety is the top priority for railways. Recent advances in technology are spurring the development of bogie monitoring systems for rolling stock that can monitor wheels for excessive vibration to prevent derailment. However, the connection of power supply cables from rail cars to sensors on existing bogies is considered impractical.

As a solution, Toshiba Corporation has developed an electromagnetic vibration energy harvester module to monitor the condition of rolling stock. The energy harvester incorporates an electromagnetic induction generator with low flux leakage and high flux concentration so that sufficient electric power can be generated even in a narrow space above the wheels.

Field tests on test rail lines confirmed that the harvester works effectively under practical conditions. Furthermore, in order to efficiently convert AC power into DC, we have developed a module that outputs power at the maximum power point. This is achieved by changing the resistance to the vibration energy harvester. Simulations using data from real locomotive vibration have verified that the newly developed module delivers double the output capacity of the conventional module. The new energy harvester module is expected to provide a significant increase in output capacity in a practical system for commercial railways.

Part of the testing of this module was performed jointly with the Railway Technical Research Institute.



R_{ac}: equivalent resistance to vibration energy harvester

Prototype vibration energy harvester module to monitor rolling stock condition

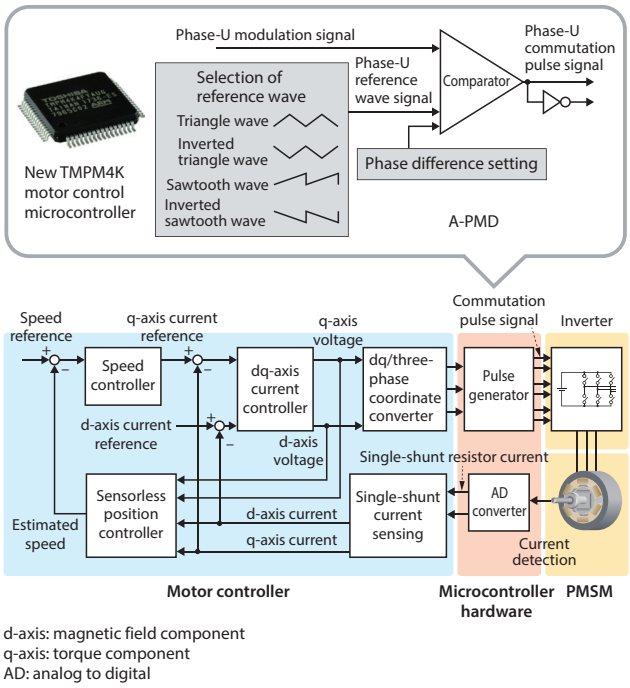
TMPM4K Group of Motor Control Microcontrollers for High-Performance, Low-Cost PMSM Drive Systems

Highly efficient permanent magnet synchronous motors (PMSMs) are now widely used for consumer and industrial applications. However, the increase in costs incurred by the expensive current and position sensors necessary for motor drive is a major obstacle to the further dissemination of PMSMs. Alternatively, advanced technology is required to achieve sensorless control of a PMSM in order to eliminate the need for expensive sensors.

To solve this problem, the Toshiba Group has developed the TMPM4K group of motor control microcontrollers featuring an advanced programmable motor driver (A-PMD) that simplifies sensorless control of the PMSM.

The A-PMD generates commutation signals required for advanced PMSM control. Single-shunt current sensing eliminates the need for a current sensor, and a sensorless position controller eliminates the need for a position sensor.

The TMPM4K group is expected to deliver high performance because of the offloading of the central processing unit (CPU) while lowering costs due to the reduced external parts count.



d-axis: magnetic field component
q-axis: torque component
AD: analog to digital

Control block diagram of PMSM drive system and TMPM4K motor control microcontroller

Ultrasonic Spot Weld Inspection Robot System

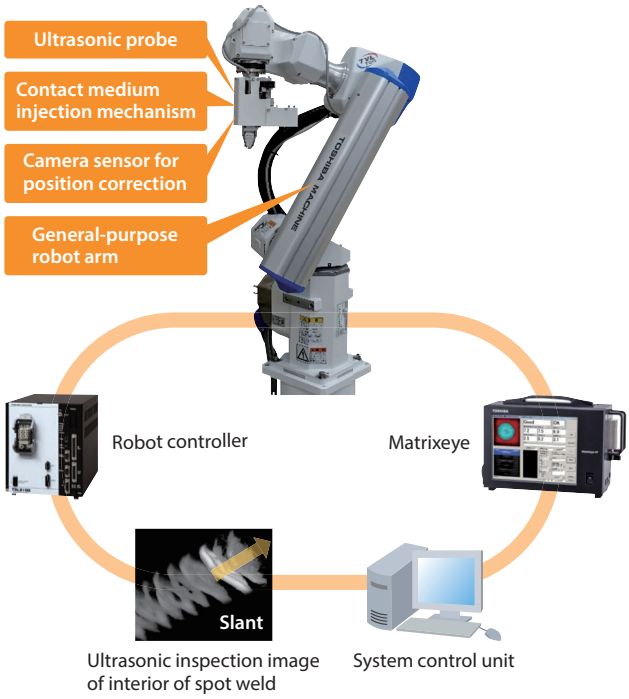
Toshiba Corporation has developed an automatic spot weld inspection robot system using the Matrixeye three-dimensional (3D) ultrasonic inspection system.

Previously, the time required for ultrasonic inspection varied according to the proficiency of the operator, because the angular alignment of the inspection probe relied on the operator's experience.

To address this situation, we have developed an algorithm to estimate the slant of the front and back surfaces of a weld and determine the appropriate posture of the inspection probe based on the distribution of ultrasonic reflection intensity in inspection images from Matrixeye.

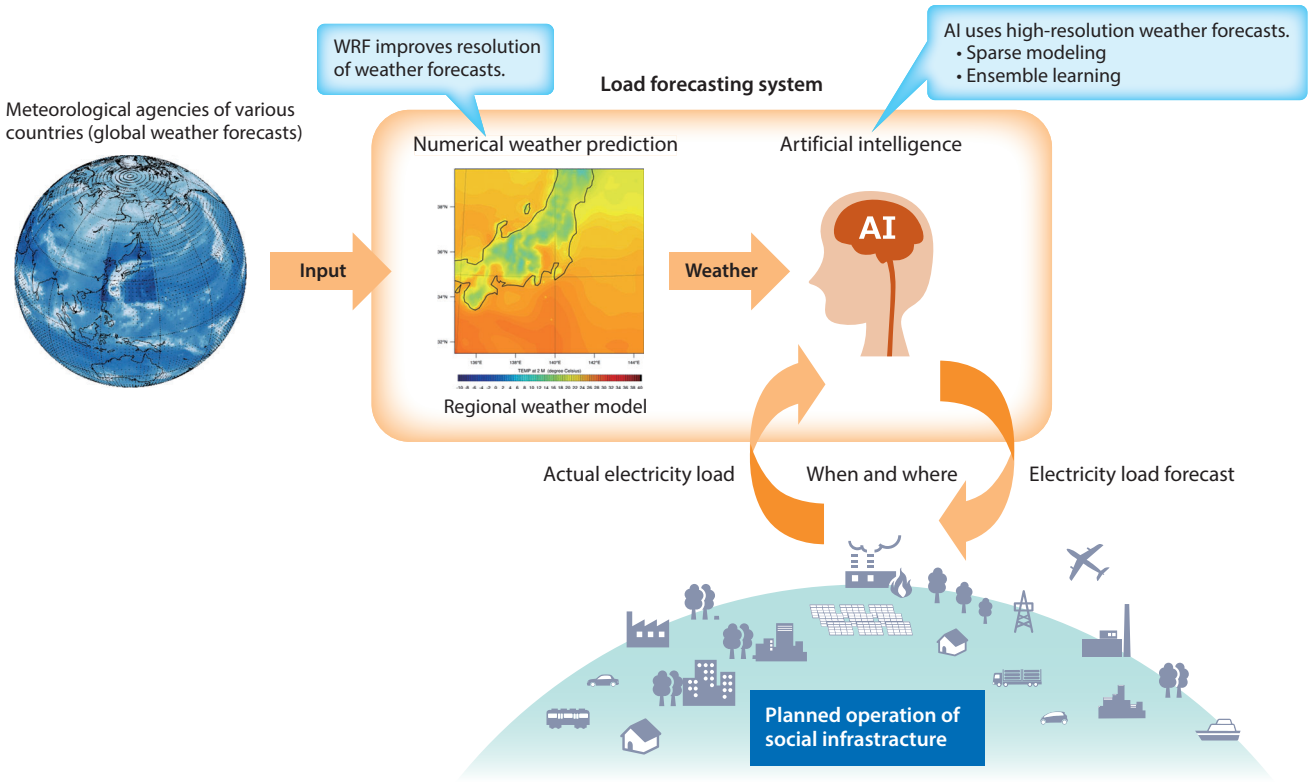
We have applied this algorithm to a robot arm incorporating an inspection probe and a contact medium injection mechanism that facilitates the passage of ultrasound, thereby realizing an automatic spot weld inspection robot system.

As the next step, we will conduct field tests to achieve practical application in fields where spot welding is widely used, including the automobile industry.



Ultrasonic spot weld inspection robot system

High-Precision Electricity Load Forecasting Technology Using Numerical Weather Prediction and Artificial Intelligence



Architecture of high-precision electricity load forecasting system

Toshiba Corporation has developed a high-precision electricity load forecasting technology that combines numerical weather prediction and artificial intelligence (AI).

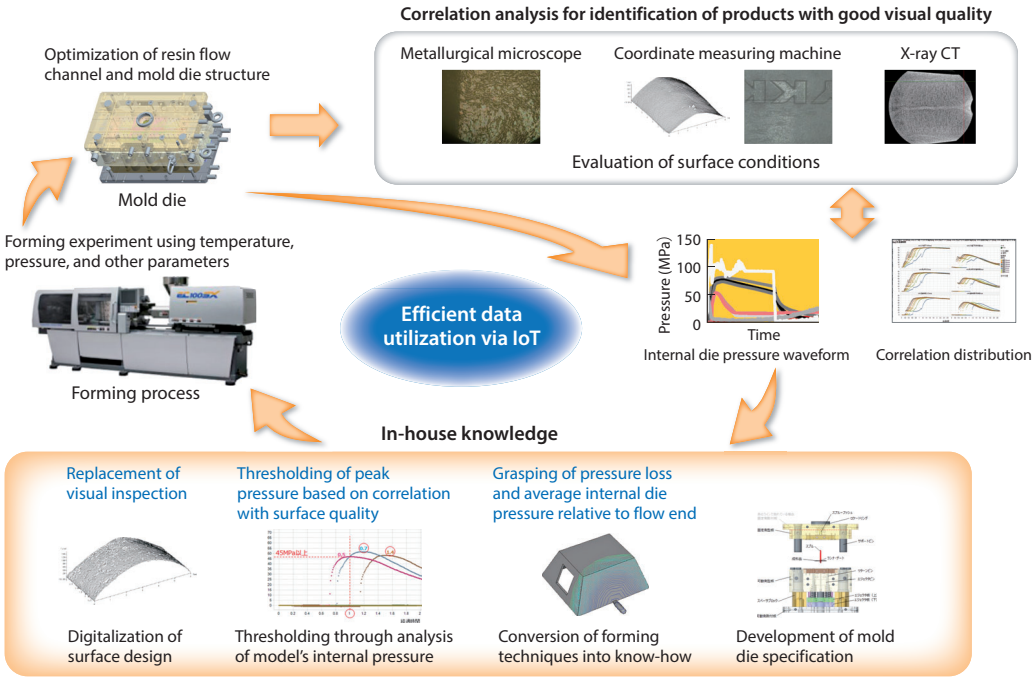
The numerical weather prediction component converts low-resolution global forecasts into high-resolution regional forecasts using the Weather Research and Forecasting (WRF) model.

The AI component converts high-resolution weather forecasts for the service areas of power companies into electricity demand using several machine learning techniques, including sparse modeling and ensemble learning.

The conventional technology requires manual selection of weather forecast variables for major cities and uses a single regression model. In contrast, the newly developed technology employs a sparse modeling technique to select weather forecast variables automatically from the entire service area and an ensemble learning technique to use several regression models.

We will apply this technology to electricity management systems and virtual power plant services.

Manufacturing IoT Solutions to Realize Smart Factories



CT: computed tomography

Manufacturing IoT solution applied to injection molding process

The application of the Internet of Things (IoT) in the manufacturing sector, known as manufacturing IoT, is attracting attention as a means of realizing smart factories. However, it is necessary to understand what it is and what can be done with it because IoT is merely a means, not an objective in itself. The use of IoT solutions can be considered in order to resolve four issues inherent in manufacturing: quality improvement, productivity enhancement, cost reduction, and the passing on of skills.

To assist in reaping the benefits of IoT at an early stage, Toshiba Corporation has systematized manufacturing IoT solutions drawing on its expertise acquired through improvement activities for various products.

For manufacturing IoT, several processes must be promoted in the factory including collection, visualization, and analysis of data; automatic control and optimization; and autonomous operation.

Our manufacturing IoT solutions make it possible to identify fundamental issues from an apparent problem that is encountered at a factory and to extract production and quality data necessary to solve the problem efficiently.

First, we have systematized the injection molding, die casting, press working, and other parts machining processes. In the case of injection molding, the data to be managed such as temperature, pressure, and speed are selected according to the causes of failure phenomena including sink marks and flash as well as countermeasures against them. Next, data are collected from injection molding machines, mold dies, and measuring instruments and utilized to optimize their settings to prevent failures.

We have been facilitating the introduction of IoT solutions by systematizing the data utilization process, encompassing data collection, data analysis methods and results, improvement actions, and expected effects. Such systematization is expected to be helpful in conducting early failure analysis and stabilizing manufacturing yields.

At present, we are working on the systematization of various processes that can be applied to a wide range of fields, such as the automation of inspection using machine learning and the prediction of equipment failure through monitoring of motor and bearing vibrations.

Furthermore, the use of the Meister series of manufacturing IoT solutions from Toshiba Digital Solutions Corporation makes it possible to create digital twins of manufacturing phenomena, supporting advanced utilization of data. A digital twin is a precise digital replica of a manufacturing process or a manufactured product for use in cyberspace.

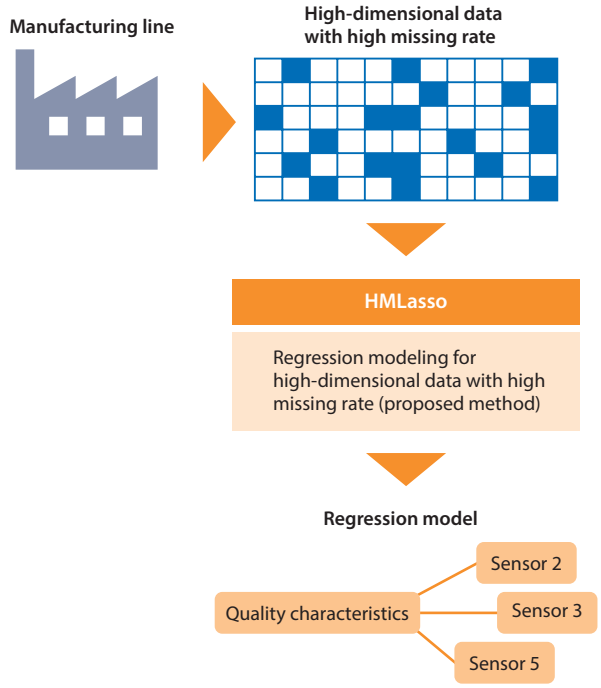
Our newly developed manufacturing IoT solutions have begun to be utilized in the manufacturing field both within and outside the company.

Regression Modeling for High-Dimensional Data with High Missing Rate

In manufacturing lines, big data is utilized to estimate regression models for quality characteristics so as to identify the causes of deterioration in quality. Specifically, the lasso (least absolute shrinkage and selection operator) method, which makes it possible to perform both variable selection and coefficient estimation, is commonly used for regression analysis of high-dimensional sensor data. However, sampled measurement data tend to have many missing values, which reduces the estimation accuracy because imputation of missing data introduces bias.

As a solution to this problem, Toshiba Corporation has developed a new method called HMLasso (lasso with high missing rate), which accurately estimates regression models without imputation, in collaboration with the Institute of Statistical Mathematics, an information and systems research organization open to all universities.

HMLasso achieves accurate estimation by utilizing information about the rates of missing data. It has been confirmed that HMLasso is theoretically superior to the existing method. Numerical benchmark simulations using HMLasso for data with a 50% missing rate showed a 43% reduction in estimation error compared with the existing method.



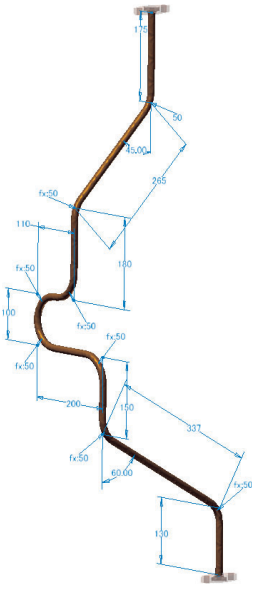
Flow of regression modeling using high-dimensional data with high missing rate

3D Piping Design Methodology to Reduce On-Site Installation Period

Since gas-insulated switchgears (GIS) are customized according to the ground conditions of the area where they are installed, they are available with various structures and layouts. In particular, the piping that supplies insulation gas to a GIS is often configured on-site to match the size of the GIS components. The piping requirements may therefore affect the installation period. Reducing the installation period of a GIS is crucial because of the need to shut down the substation concerned during its installation.

In response to this situation, Toshiba Corporation has realized the prefabrication of gas piping through two measures. One is 3D design that combines piping pattern control through equipment layout standardization and flexible piping layout rules that simplify customization. The other is 3D gas piping drawings developed through collaboration of the design and production departments, which show 3D dimensions and processing methods.

In an actual project, we succeeded in connecting 70 pipes without any on-site processing, reducing the time required for piping work to one-quarter. This is equivalent to a 55% reduction of the overall installation period. We will also apply this prefabrication technique to electric wiring piping to further reduce the installation period.



3D drawing with dimensions for gas piping manufacturing instructions

Example of GIS equipped with gas piping

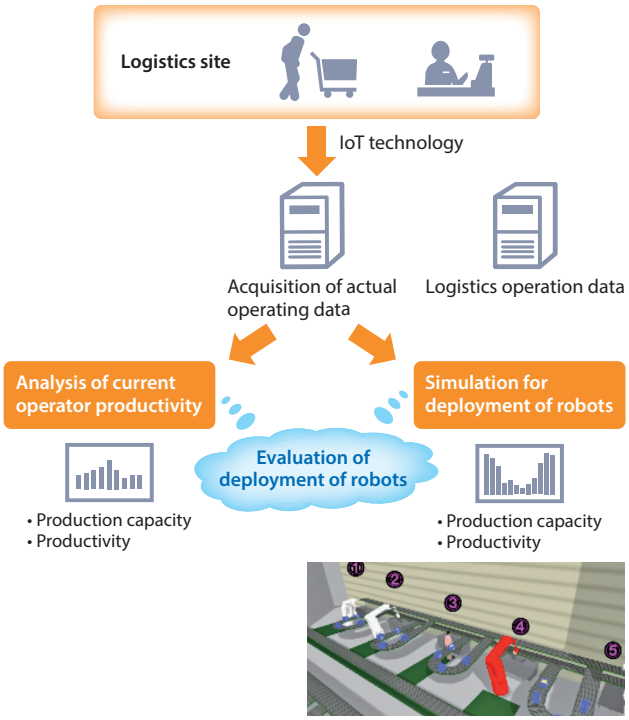
Application of Production Line Simulation Technologies to Logistics Field

Accompanying the ever-increasing demand for logistics services, the logistics industry is facing a serious labor shortage. To solve this problem, Toshiba Corporation has developed an automated depalletizer, picking robots, and other automation machines for logistics applications. To enhance customer satisfaction in this field, however, it is necessary to offer not only robotics hardware but also total logistics solutions.

We have been utilizing simulation technologies to construct new production lines, verify production capacities, and improve productivity at various factories, including those manufacturing infrastructure products and semiconductor devices.

We have now applied these technologies and solutions to logistics systems, including the layout for logistics lines where a large variety of items are handled and workloads vary considerably. These simulation technologies make it possible to optimize the layout of logistics lines on which both human operators and machines are working, and to evaluate the capacities of logistics systems and the effects of robotic automation prior to the construction of logistics lines.

To further enhance customer value, we will offer logistics solution services using these technologies including analysis of the present situation, proposal of improvement measures, and deployment of automation robots.



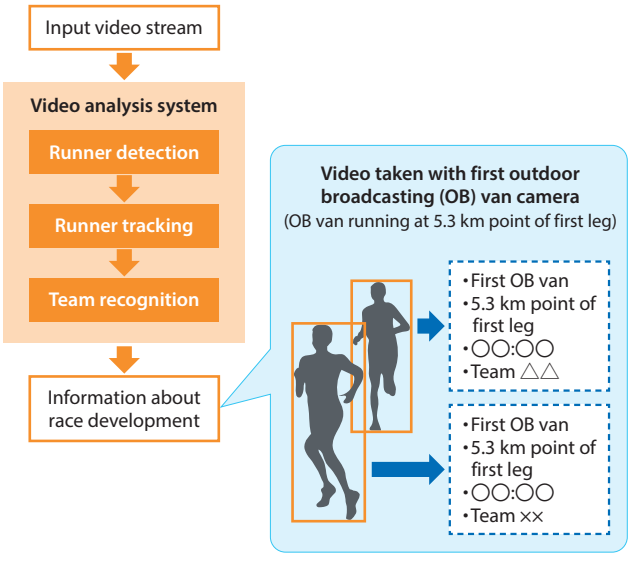
Application of production line simulation techniques to logistics field

Accurate Real-Time Recognition of Road Relay Race Teams in Video Images Using Deep Learning

Toshiba Corporation has developed a real-time video analysis system for road relay races that automates the recognition of images of runners' teams, improving the efficiency of live TV production.

It is difficult to recognize runners' teams in a road relay race because of frequent blocking of their view and constantly changing outdoor lighting conditions. The newly developed real-time video analysis system uses a deep-learning model to recognize runners' teams based on their uniforms, which are easy to track even when runners overlap. This deep-learning model provides robust team identification by learning uniform logos and colors under various outdoor lighting conditions. In addition, this system excludes roadside spectators from recognition based on differences in movement between runners and spectators, reducing false detection and processing cost.

We have conducted a demonstration experiment with the aim of reducing the effort required to manually check runners' teams when displaying information about runners and lap times in a broadcast video. The new video analysis system achieved a practical team recognition accuracy of 98.1% in live broadcasting. This technology can also be used for video analysis in other sports, as well as for factory work analysis to improve production efficiency using existing surveillance cameras.



Outline of video analysis system for live broadcasts of road relay races

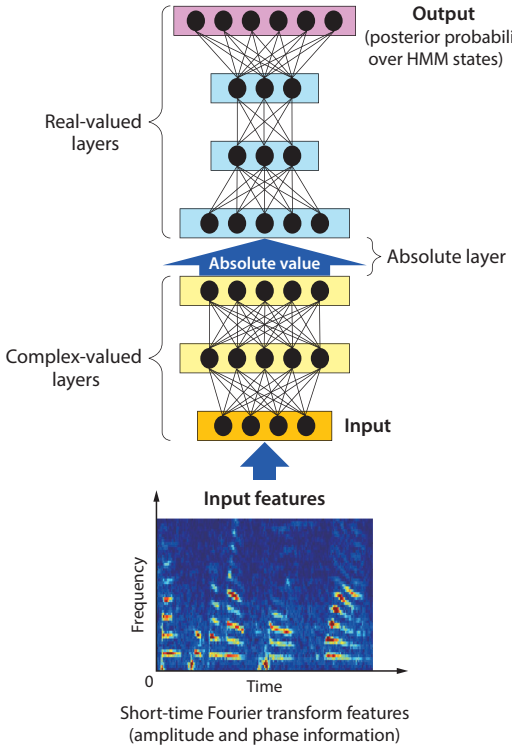
Complex-Valued Neural Network Acoustic Model for High-Accuracy Speech Recognition

Toshiba Corporation has developed a complex-valued neural network (CVNN) acoustic model that processes the phase information of a speech signal to improve the accuracy of speech recognition.

A conventional acoustic model for speech recognition processes only the amplitude information of a speech signal using a real-valued neural network. In contrast, a CVNN, which can naturally process both the amplitude and phase information of a speech signal, makes it possible to capture more detailed speech features.

It was previously difficult to use a CVNN for an acoustic model because of the instability of CVNN training. To solve this problem, we have developed a batch amplitude mean normalization (BAMN) technique for rapid and stable training of a CVNN. BAMN is performed by dividing a mini-batch of complex-valued features by its mean absolute value while maintaining the phase information. We have also developed a CVNN architecture suitable for speech recognition.

As a result of these innovations, the CVNN acoustic model has achieved better speech recognition performance than a conventional real-valued neural network acoustic model under noisy conditions. We will apply the CVNN acoustic model to speech recognition applications used under noisy conditions.



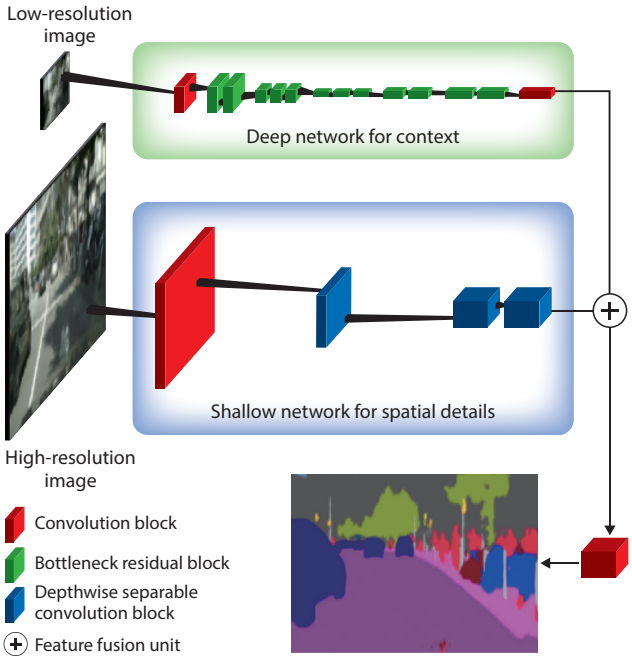
CVNN architecture for acoustic model

ContextNet: Accurate Real-Time Semantic Segmentation with Low Memory Requirement

Toshiba Corporation has developed a semantic segmentation technique called ContextNet that satisfies the need for both real-time processing and high accuracy with a low memory requirement.

ContextNet classifies each pixel in an input image into a class such as car, pedestrian, road, or sidewalk with high accuracy for autonomous driving, which requires real-time processing. It is a deep neural network (DNN) combining a deep branch at low resolution that efficiently captures global context information with a shallow branch that focuses on high-resolution segmentation details.

In a performance evaluation with a dataset called Cityscapes, ContextNet with 0.85 million parameters has achieved a 66.1% accuracy at 41.9 frames per second, outperforming other state-of-the-art real-time methods.



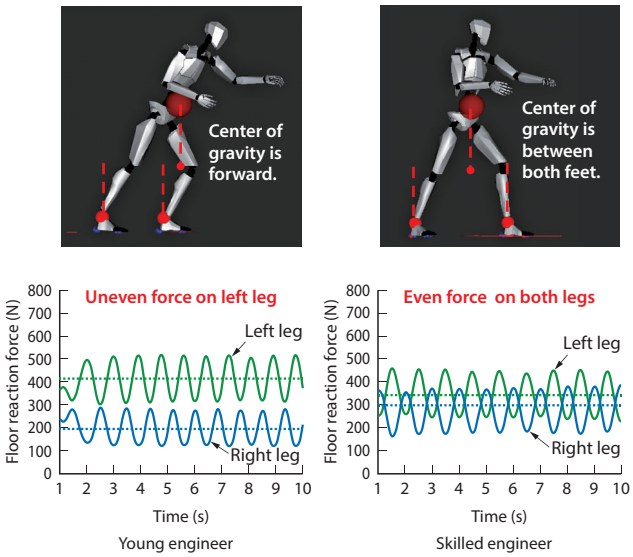
Network structure of ContextNet

Visualization of Skilled Work Performance Using Motion Capture

In the manufacturing industry, the process of finish machining requires a great deal of manual work. It is therefore important to pass on the knowledge and expertise of skilled engineers to young engineers.

For this purpose, Toshiba Corporation has developed a technique to visualize physical exertion using motion capture and musculoskeletal simulation. Inertia sensor-based motion capture can measure the motion of the whole body while an engineer works on equipment. Joint torque and muscular power can be estimated through inverse kinematics analysis of a body model. In addition, the floor reaction force of both feet can be estimated without a force sensor by assuming that both feet are fixed to the floor.

We compared the action force applied to the feet of both skilled and young engineers. As a result, it became clear that the skilled engineer maintains a posture that imposes little burden on the muscles. The newly developed technique makes it possible to obtain the characteristics of motions. We are also using this technique to train young engineers toward their participation in Skill Olympics competitions.



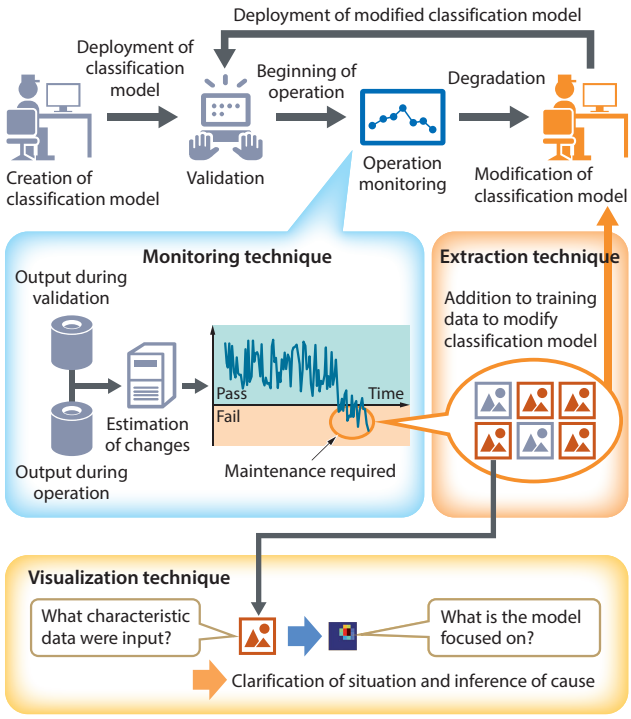
Comparison of muscle loads of young and highly skilled engineers by means of motion capture

Techniques for Maintenance of Deep Learning Models

As the industrial application of deep learning expands, some classification models have been used for extended periods of time. There are various forms of inputs for classification models, including images captured by cameras and electrical signals from sensors. However, factors such as changes in the targets of imaging or misalignment of sensors could affect the characteristics of input data, degrading the accuracy of classification. To ensure stable operation, it is necessary to monitor changes in the characteristics of input data and to modify the classification models or correct the sensor alignment accordingly so as to normalize the input data characteristics.

To address this requirement, Toshiba Corporation has developed (1) a monitoring technique to monitor changes in output data of a classification model from the time of creating the model, (2) an extraction technique to find distinctly unusual input data, and (3) a visualization technique to show what the classification model is focused on.

The extraction and visualization of input data help to clarify the situation and infer the cause of degradation. These data are also useful as training data for the modification of classification models. Efficient maintenance of classification models has been realized by combining these monitoring, extraction, and visualization techniques.



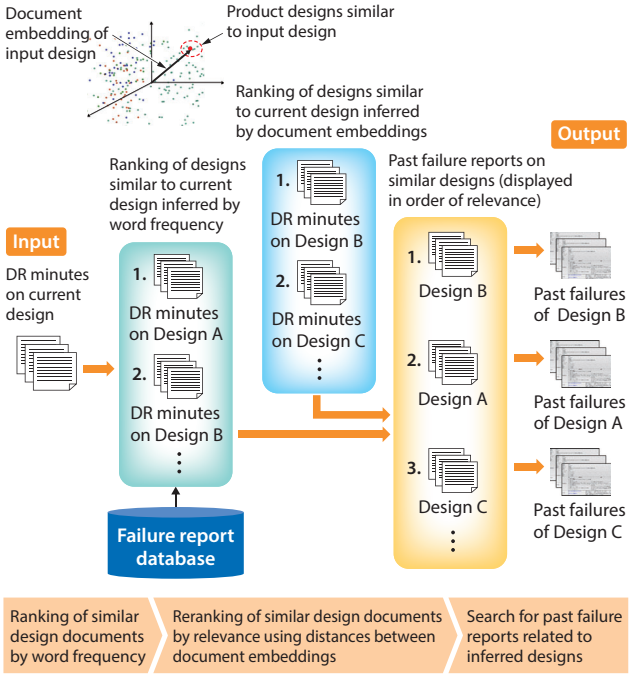
Monitoring, extraction, and visualization techniques to maintain accuracy of deep learning models

Document Retrieval Technique to Effectively Search for Past Failure Reports

In product design, it is important to understand past failures in order to avoid repetition of the same failure. Although experienced engineers with extensive knowledge can find appropriate failure reports on existing products similar to a product currently at the design stage from among a large number of search results, it is not an easy task for young engineers. This could lead to serious failures.

To deal with this situation, Toshiba Corporation has developed a high-accuracy document retrieval technique to extract past product design documents similar to the documentation of a product that is currently being designed. Based on the assumption that products with similar considerations for design review (DR) meetings have similar design specifications, the newly developed document retrieval technique extracts past design documents whose DR minutes are similar to those of the current design. Similarities between DR minutes are calculated based not only on word frequency but also on document embeddings learned by neural networks.

The results of an experiment have shown that the recall ratio of the top 30 search results using the new technique is 75.4%, 7.1 points higher than that using the conventional method based only on word frequency. The new document retrieval system is currently being tested at one of the Toshiba Group's offices.



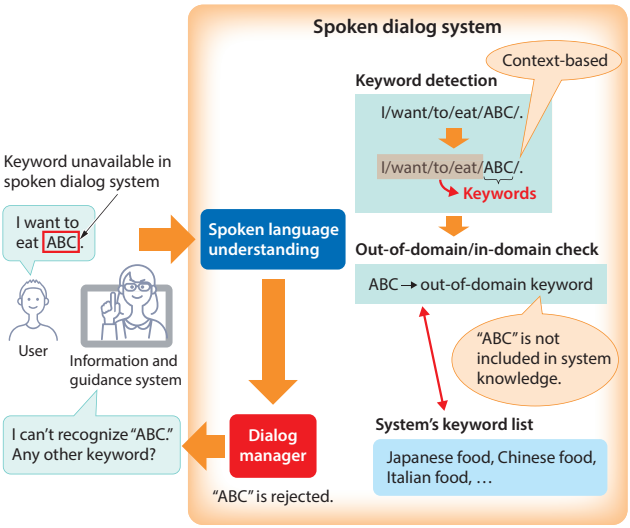
Document retrieval technique to search past reports of problems with existing products similar to product currently at design stage

Out-of-Domain Keyword Detection Technique for Spoken Dialog Systems

A spoken dialog system that interacts with users to provide information and guidance collects and retains keywords uttered by users in advance and generates responses based on the collected keywords. Since it is difficult to add all new product names and buzzwords that appear one after another to the keyword list, a spoken dialog system often encounters unknown (out-of-domain: OOD) keywords in users' speech. In such cases, the spoken dialog system cannot generate an appropriate response. In contrast, a spoken dialog system with OOD keyword detection capability can notify users that their request cannot be understood and should be rephrased.

Toshiba Corporation has proposed an approach to the detection of OOD keywords based on the context of user utterances. For example, from the utterance "I want to eat ABC," a spoken dialog system can detect the keyword "ABC" through machine learning models using the context "I want to eat ..." that is commonly used in relation to food. The system treats the detected keyword as OOD if it is not included in its keyword list.

Our spoken dialog system is expected to be used at information desks in shopping centers or as question-answering systems at call centers where new product names appear frequently.



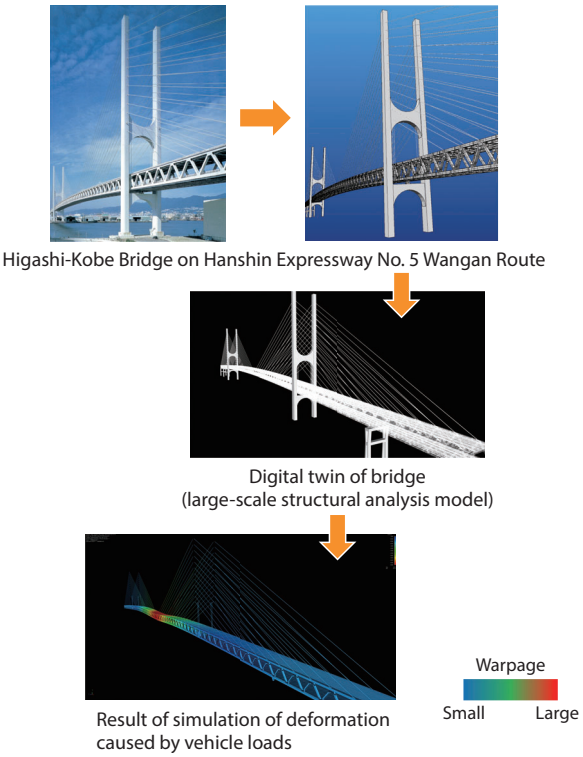
Out-of-domain keyword detection technique for spoken dialog systems

Ultra-Large-Scale Structural Analysis of Bridges Applying Digital Twins

Toshiba Corporation has developed an ultra-large-scale structural analysis technology to create digital twins of real-world bridges. A digital twin is a precise digital replica, or cyber representation, of a physical asset, which is used to optimize the design, operation, and maintenance of that asset.

Conventional analysis techniques model entire bridges by representing their complex cross-sectional structures with simplified parameter-fitted beams. The newly developed ultra-large-scale structural analysis technology is much more precise and true to the original, and can reproduce a bridge in detail at a scale approaching 500 million degrees of freedom. Representing the complexity of real structures helps to realize direct analysis of where stress concentration will occur, making it possible to enhance disaster prevention through assessment of structural soundness.

We have constructed a model of the Higashi-Kobe Bridge on the No. 5 Wangan Route through collaborative research with Hanshin Expressway Co., Ltd. Without parameter fitting of the model, the simulated bridge deformation due to the loads of two vehicles of 20 tons each was in good agreement with the measured results, successfully demonstrating the effectiveness of ultra-large-scale structural analysis using digital twins.



Example of simulation of bridge deformation applying ultra-large-scale structural analysis

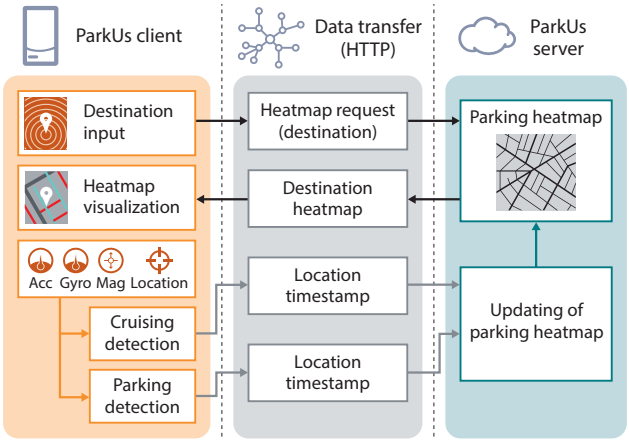
ParkUs Parking Space Monitoring Technology Applying Behavior Analysis

The search for a parking space on a daily basis can lead to various social problems including unnecessary carbon dioxide (CO_2) emissions, wasted time, squandered fuel, and traffic congestion.

To solve this issue, Toshiba Corporation has developed ParkUs, an algorithm that provides information on parking space availability in real time. ParkUs does not require the installation of cameras or sensors on infrastructure. Instead, it automatically builds up a map of parking spaces by detecting cruising behavior via machine learning using sensors such as accelerometers and the Global Positioning System (GPS) in smartphones and car navigation systems.

In several evaluation trials with more than 200 recorded journeys by 27 users, ParkUs achieved a detection accuracy exceeding 80%. The use of this system also resulted in a roughly 50% reduction in the time required to find a parking space, from more than 3 minutes on average to 1 minute and 37 seconds.

In a city with a population of 400 000, ParkUs could reduce CO_2 emissions by approximately 790 tons and save about half a million U.S. dollars in fuel costs annually. This technology could also be applied to detect queuing in visitor spaces in real time.



HTTP: Hypertext Transfer Protocol
Acc: accelerometer
Gyro: gyroscope
Mag: magnetometer

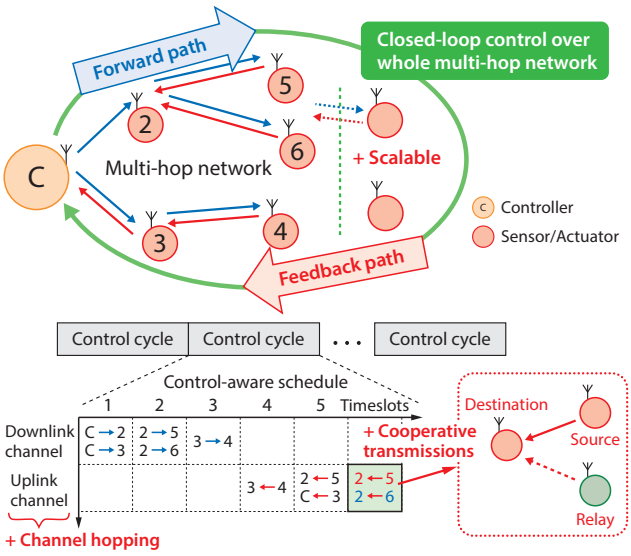
Architecture of ParkUs system to find parking spaces through behavior learning

Wireless Connectivity over Multi-hop Networks to Realize Industrial Closed-Loop Control

Beyond Industry 4.0, smart network environments will allow for the monitoring and control of everything. Toshiba Corporation has developed a state-of-the-art wireless technology based on an advanced control-aware scheduling algorithm so as to realize closed-loop control over multi-hop networks, which is expected to provide ultra-low and deterministic latency. This wireless technology can be combined with channel-hopping and cooperative transmissions involving multiple nodes to achieve ultra-high reliability. The low-overhead signaling mechanism for distributed operation can also provide scalability in wireless network deployments.

The new technology enables stable control loops with a deterministic cycle time of less than 10 ms for up to 100 multi-hop source nodes while guaranteeing a reliability of more than 99.999%. It can be used for versatile control and other industrial applications, including discrete manufacturing, process control, remote operation of mobile robots, formation control of drones, and automated guided vehicles. We consider that it will also serve as a replacement for cable-based control to realize wireless control of various emerging industrial applications.

The new technology can be implemented on any off-the-shelf wireless chipsets, including Bluetooth® and Wi-Fi chipsets. Having completed a proof of concept at our laboratory, we are currently preparing for field trials to demonstrate the new technology for industrial applications.



Example of network and protocol configuration for closed-loop control over wireless multi-hop network

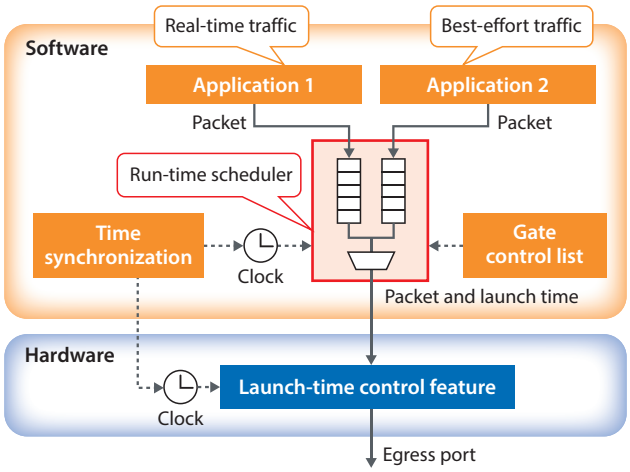
The Bluetooth® work mark and logo are registered trademarks owned by Bluetooth SIG, Inc.

Software-Based Run-Time Scheduler for Real-Time Communication

There is increasing interest in the use of time-sensitive networking (TSN) technology to satisfy strict constraints on real-time communication. Industrial automation and in-vehicle networks are two typical examples of TSN applications that require real-time communication.

In order to meet the diverse real-time requirements of these applications, Toshiba Corporation has developed a software-based run-time scheduler that is compliant with the time-aware shaper specified in the Institute of Electrical and Electronic Engineers (IEEE) 802.1 TSN standard. The design of the newly developed run-time scheduler adopts a software-based approach without the use of a dedicated custom logic chip. In particular, it prefetches scheduling information from a gate control list(*) before it is known to be needed. Based on the scheduling information, the scheduler dynamically determines a launch time for each frame.

As a proof of concept, we have created a prototype system by combining the run-time scheduler and a network interface card with a launch-time feature. The results of an evaluation of this system show that the new design significantly reduces jitter in real-time streams (to less than 0.1 µs), regardless of the interfering best-effort traffic. As the next step, we will optimize the new approach to reduce end-to-end latency.



Block diagram of software-based traffic scheduler for real-time communication

(*) A list defined in the IEEE 802.1Qbv standard that specifies the time intervals and states of gates

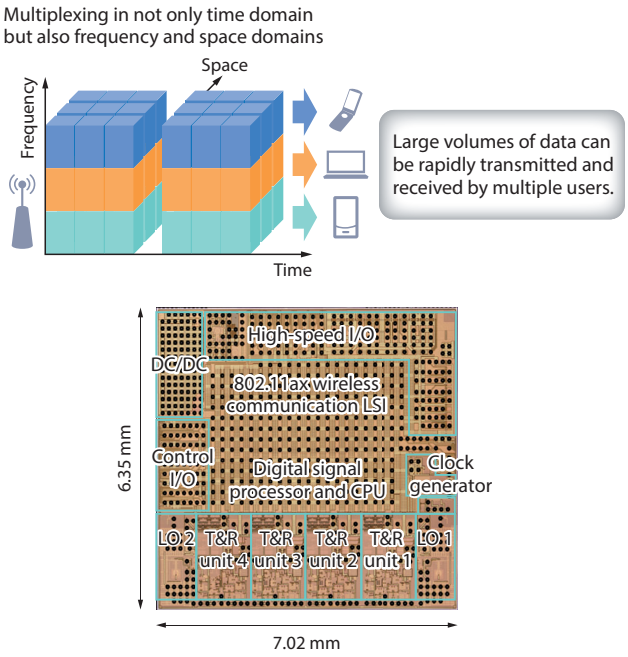
Next-Generation Wireless LAN Technology for High Efficiency and Reliability

Toshiba Corporation has developed a radio communication large-scale integration (LSI) chip compliant with the draft IEEE 802.11ax standard for a next-generation wireless local-area network (WLAN) with higher efficiency and reliability than conventional WLANs.

In addition to multi-user multiplex transmission techniques that enable multiple users to communicate with one another simultaneously, the newly developed LSI chip provides the world's lowest signaling error(*), making it possible to use 1024-QAM (quadrature amplitude modulation) to transmit more information at once. These features help to prevent throughput degradation in congested environments, achieving high-speed wireless communication at a maximum data rate of 2.165 Gbit/s. Furthermore, this LSI chip can detect interference signals from various sources including microwave and other wireless systems by extracting the characteristics of radio signals.

This technology is expected to be utilized in various situations such as stadium WLAN services and IoT applications incorporating many wireless sensors.

(*) As of February 2018 for LSI chips for WLANs (as researched by Toshiba Corporation)



DC/DC: DC/DC converter I/O: input/output
T&R: transmitting and receiving LO: local oscillator

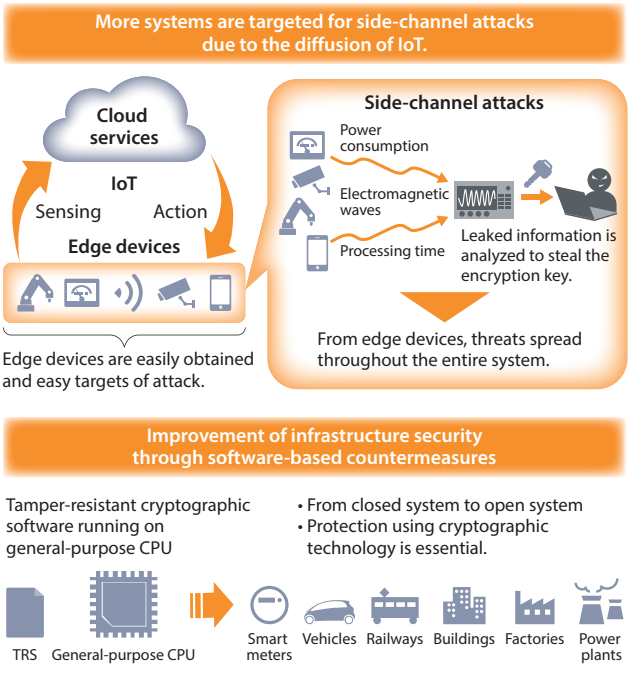
Overview of multi-user multiplex transmission technique and newly developed LSI chip for radio communication

Cryptographic Software Implementation Technology

Side-channel attacks are attack methods that monitor analog information leaked during cryptographic processing (e.g., power consumption, electromagnetic waves, and processing time) to recover a secret key. Although side-channel attacks have been addressed as a real threat in the field of smart cards, attacks on IoT edge devices in infrastructure systems are still a threat.

As a countermeasure against this threat, Toshiba Corporation is developing a cryptographic software implementation technology that can easily be applied to existing systems and run on a general-purpose CPU. Implemented as software, it is updatable to sustain protection against ever-evolving attacks and simplify the maintenance of security, even for systems with a long product life.

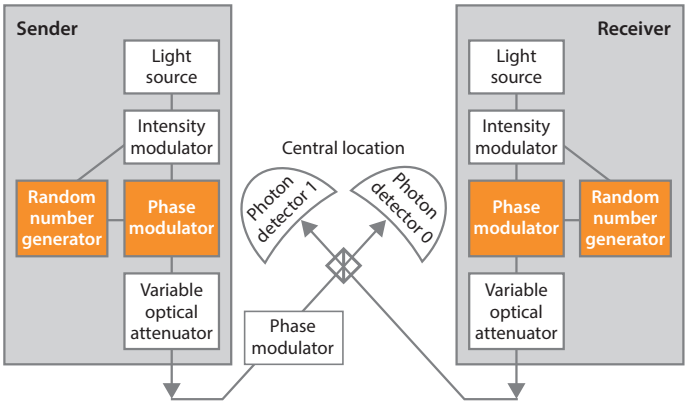
To date, we have developed a software-based countermeasure technology that implements cryptographic hash-based message authentication code (HMAC) algorithms used for device authentication and data integrity verification in IoT systems. An evaluation based on the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 17825 standard, one of the official test metrics, has confirmed that it is resistant to side-channel attacks.



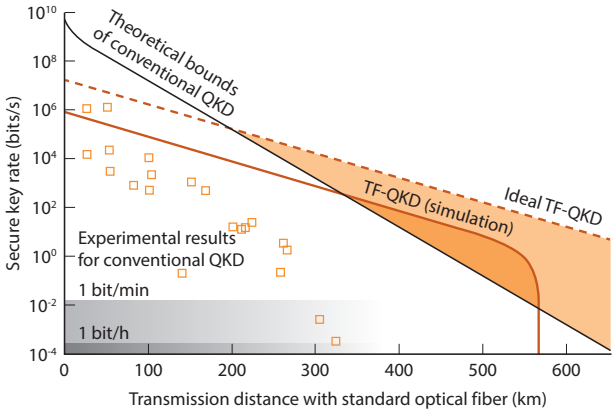
TRS: tamper-resistant software

Cryptographic software implementation technology to protect edge devices of IoT systems from side-channel attacks

Twin-Field QKD Allowing Secure Quantum Key Distribution over More than 500 km of Optical Fiber



Setups for implementation of twin-field quantum key distribution (TF-QKD)



Theoretical limits and experimental data of fiber-based quantum schemes

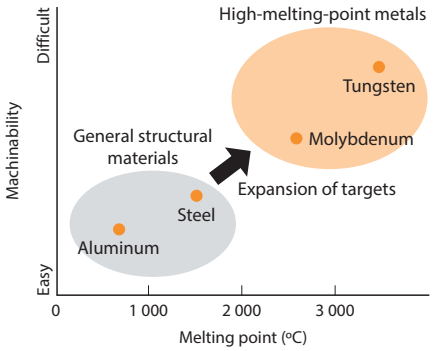
Toshiba Corporation has developed a new protocol for quantum key distribution (QKD) that will extend its range to more than 500 km of standard telecom fiber(*). This advance, called twin-field QKD, enables the protection of sensitive data transmitted in optical networks between cities such as London, Paris, Brussels, Amsterdam, and Dublin.

Up until now, the typical range of QKD has been limited to a few hundred kilometers of optical fiber. This is because the photons carrying the information can be scattered and thereby lost from the fiber, reducing the rate at which secret keys can be formed. We have now discovered a way to enhance the key rate and transmission distance of QKD, potentially allowing fiber links beyond 500 km for the first time. The final secure key rate can be orders of magnitude greater than that obtainable with existing protocols.

In conventional QKD, single photons are sent from one end of the fiber to the other end. In the case of twin-field QKD, on the other hand, light pulses are sent from both ends of the fiber to a central location, where a photon is detected. A simulation has shown that the light pulse emitter and the single photon detector work in the same way as conventional QKD and that the transmission distance is increased to up to double without compromising security or the key rate.

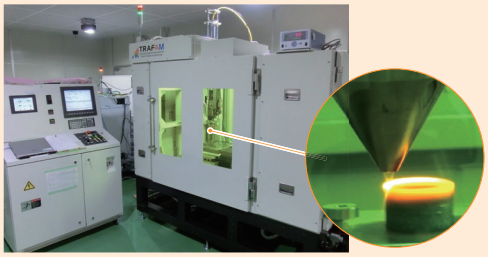
(*) The details of this breakthrough were published in the May 2, 2018, issue of the scientific journal *Nature*.

Development of Technique for 3D Metal Printing of High-Melting-Point Metals and 3D Metal Printer Offering World's Highest-Class Building Speed of 510 cm³/h

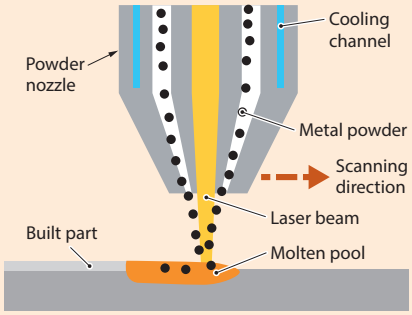


Comparison of metal material properties

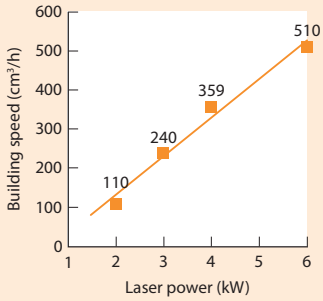
Heat dissipation part made of tungsten



Prototype high-speed 3D metal printer



Powder nozzle of 3D metal printer applying LMD



Relationship between building speed and laser power

3D metal printers are capable of building metal parts directly from 3D computer-aided design (CAD) models. 3D metal printing technology is expected to be used to build high-mix low-volume parts such as metal molds and functional components. However, its industrial application has been limited because of constraints on the usable materials and slow building speed.

Toshiba Corporation has been developing 3D metal printing technologies to realize the use of various types of metals. For example, powder bed fusion is a 3D printing process whereby thinly spread metal powder is selectively melted and solidified with a laser beam, layer by layer. In this process, the properties of the metal powder are an important factor in improving the quality of the built parts.

We have collaborated with Toshiba Materials Co., Ltd. to develop powders of high-melting-point metals optimized for 3D printing. For example, tungsten, which is used to manufacture various items including heat-resistant parts, is difficult to machine. We have optimized the shape and size of tungsten powder as well as the printing conditions to enable the 3D printing of tungsten parts.

We have also developed a high-speed laser metal deposition (LMD) 3D metal printer and its powder nozzle under a project of the Technology Research Association for Future Additive Manufacturing (TRAFAM). In the LMD process, which uses a laser to melt the metal powder ejected from the powder nozzle and deposit the molten metal on the substrate surface, the powder nozzle is the key to achieving high building performance. In the case of high-melting-point metals, however, the powder nozzle is subject to damage due to heat. To solve this problem, we have fabricated a cooling channel inside the nozzle to cool the tip, increasing its resistance to heat. We have also utilized fluid simulation to optimize the powder flow path, improving the focusing of the powder and thereby increasing the working distance between the point at which melting occurs and the powder nozzle and reducing the adverse effect of heat. As a result, the powder utilization efficiency and the building speed have been increased. We have also optimized LMD process conditions such as the nozzle scanning speed and laser beam width to achieve the world's highest-class building speed(*) of 510 cm³/h with a 6 kW LMD printing system.

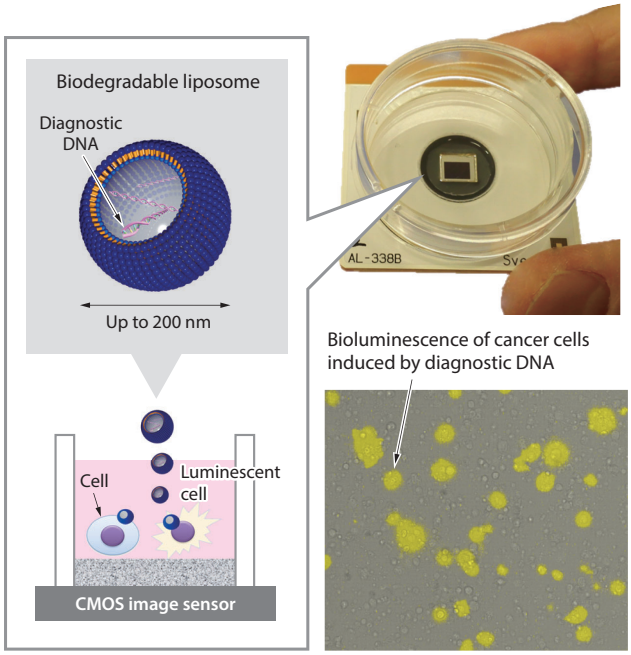
(*) As of August 2018 (as researched by Toshiba Corporation)

Live Cell Analysis Technology Using Biodegradable Liposomes

Toshiba Corporation has developed a live cell analysis technology to visualize gene activity in live cells without the need for a microscope. This technology provides time-lapse imaging of gene activity in a single cell in addition to the conventional detection of genomic sequence mutation. It is expected to improve the accuracy of breast and other cancer diagnoses as it is capable of detecting gene activity related to the growth of cancer cells as well as abnormalities in genome structures.

This technology consists of our proprietary biodegradable liposomes and a complementary metal-oxide semiconductor (CMOS) image sensor. The biodegradable liposomes serve as a nano-tool to deliver encapsulated diagnostic DNA to live cells with little damage. The cells transfected with the diagnostic DNA produce bioluminescence, depending on the activity of the targeted gene, which is imaged in real time by the CMOS image sensor.

Toward the clinical application of this technology, we have demonstrated that it allows time-lapse observation of gene activity using cells collected from breast cancer patients.



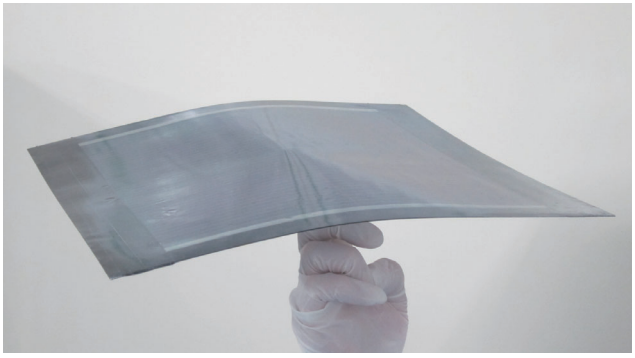
Method for detection of breast cancer cells by means of live cell analysis system using biodegradable liposomes

World's Largest Film-Based Perovskite Photovoltaic Module with World's Highest Recognized Power Conversion Efficiency

The perovskite photovoltaic cell is a type of solar cell that utilizes a crystal-structured compound called perovskite. This type of photovoltaic cell is economical because it can be created using a printing process. The perovskite photovoltaic cell is also expected to deliver high power conversion efficiency(*1). It is difficult, however, to increase the cell size and efficiency at the same time.

Toshiba Corporation has overcome this issue by using a unique printing technology together with a newly developed process. As a result, we have developed the world's largest film-based perovskite photovoltaic module(*2), with an area of 703 cm^2 (24.15 × 29.10 cm), which exhibits a power conversion efficiency of 11.7%(*3). The newly developed module has been recognized as the perovskite submodule with the world's highest power conversion efficiency in version 52 of the "Solar cell efficiency tables," which are world-renowned tables of data measured by an independent organization and published twice a year in *Progress in Photovoltaics*, a monthly academic journal.

This work has been conducted as part of the "Development of High Performance and Reliable PV Modules to Reduce Levelized Cost of Energy" project sponsored by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.



Film-based perovskite photovoltaic module

(*1) The ratio of output electric power to the radiant power incident to a solar module

(*2) As of November 2018 (as researched by Toshiba Corporation)

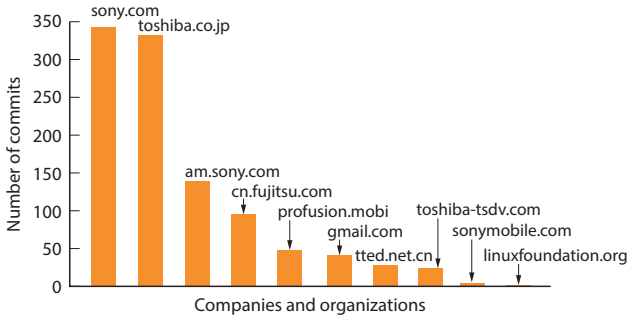
(*3) Measured by the National Institute of Advanced Industrial Science and Technology (AIST) of Japan, an internationally recognized testing organization

Fuego Automated Testing System for Efficient Testing of Linux Embedded Systems

Fuego is a flexible test automation tool developed to address the unique requirements of embedded Linux testing. Contributors around the world are working on Fuego since it is open-source software.

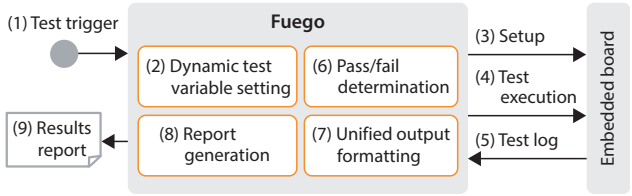
As a participant in the development of Fuego, Toshiba Corporation has been designated as a Top Contributor in recognition of its role in the development of valuable functions, including report generation, pass/fail determination, dynamic test variable setting, and unified output formatting. Currently, Fuego supports more than 100 test suites, and the project is under active development. The results of this collaborative effort, available free of charge, have helped to improve our testing productivity.

In the next phase, we aim to enhance the integration of Fuego into an open-source automated testing ecosystem.



*Surveyed on November 5, 2018

Companies and organizations contributing to development of Fuego automated testing tool for Linux embedded systems



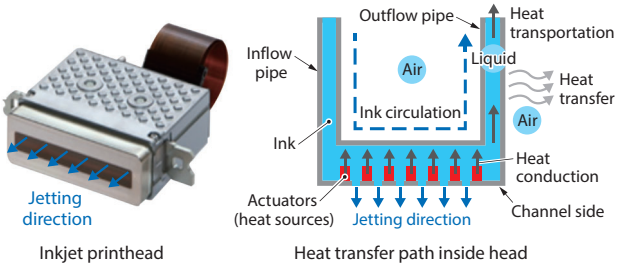
Configuration of Fuego and core components developed by Toshiba

Thermal Management Technology for Industrial Inkjet Heads

Ink recirculating type inkjet heads prevent ink deterioration and sedimentation by means of an ink recirculation mechanism for all channels, thereby ensuring stable print quality. Inkjet actuators are mounted closely together in these heads to achieve high-resolution printing. Because of the high heat density generated by this dense actuator arrangement, high cooling performance is required for such inkjet heads to prevent ink deterioration caused by a rise in temperature.

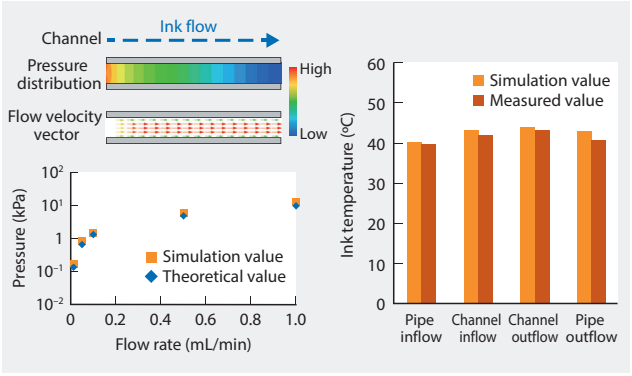
As a solution to this problem, Toshiba Corporation has developed a thermal design method applying thermal gas-liquid fluid simulation to accurately predict ink temperature distribution. We have created a detailed model of the microchannels formed by inkjet actuators, making it possible to predict ink flow behavior by calculating the friction loss on the inner channel surfaces based on a theoretical formula. This model provides a close match between the simulated and theoretical results for ink pressure and flow velocity, making it possible to accurately predict ink temperature distribution through simulations.

We have confirmed that the temperature distribution of an entire head including its parts and ink matches the measured results. By using this thermal management technology at an early stage of head design, a head structure that satisfies product specifications can be created without prototyping.



Inkjet printhead

Heat transfer path inside head



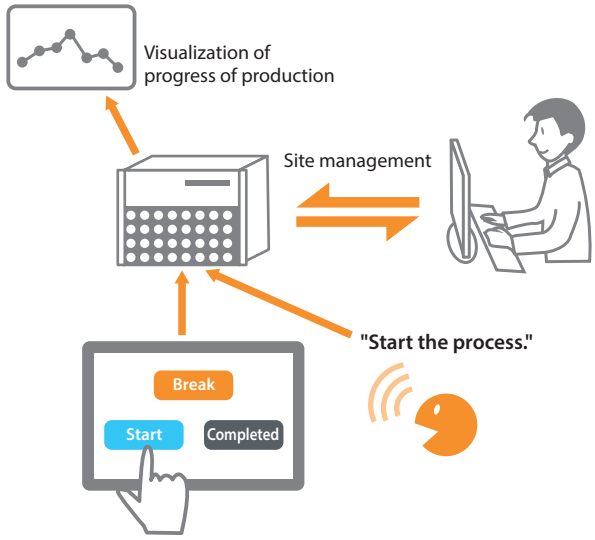
Thermal fluid analysis of microchannels between actuators

Prediction of ink flow and temperature inside inkjet head using thermal fluid analysis

Construction of System to Collect Information on Progress of Manufacturing of Customized Products

Toshiba Corporation has been utilizing a system to measure the number of person-hours required for production processes in real time, showing key performance indicators (KPIs) for production control and improvement. In the case of customized products, however, the different specifications of each product require different assembly times. In addition, there are large variations in the times required for adjustment and inspection. We have improved the production processes for customized products by analyzing the differences between the actual and estimated person-hours required. Despite these efforts, issues remained in terms of the workload required to collect data on person-hours and the inability to collect such data in real time.

To resolve these issues, we have now developed a system to collect and visualize information on the progress of manufacturing that only requires factory operators to push the Start, Break, or Completed button when starting a process, taking a break or leaving the workplace, or after having completed the process, respectively. This system makes it possible to collect real-time information on the progress and status of each manufacturing process and to halve the time required for production supervisors to manage these processes.



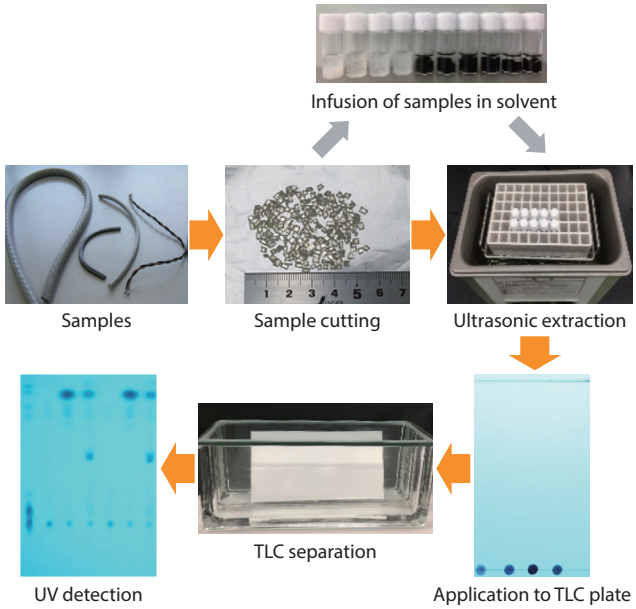
Input and utilization of information on progress of manufacturing of customized products

Simplified Method for Screening Phthalates

Toshiba Corporation has developed a simplified method for screening phthalates, which are used as a plasticizer for polyvinyl chloride (PVC) and other plastics. The European Union has adopted a decision to amend the Restriction of Hazardous Substances (RoHS) Directive so as to impose restrictions on the use of four phthalates for electrical and electronic equipment sold in the EU, which entered into force in July 2019. In order to manage the use of the restricted phthalates, a simplified screening method is needed for acceptance inspections and quality control in manufacturing processes.

The newly developed method extracts phthalates from materials using a solvent and applies the extracted liquid to a thin-layer chromatography (TLC) plate. The TLC separation results are detected under ultraviolet (UV) light. The new method requires 1/40th to 1/100th the quantity of solvent compared with the conventional method in the extraction process and simplifies the inspection process.

In addition, TLC measurement allows multiple samples to be inspected simultaneously and UV detection using image processing provides a definitive threshold value (0.1 wt%) for acceptance. Furthermore, the new method requires only 1/50th the initial cost of the conventional method and significantly reduces running costs.



Flow of simplified screening of phthalate esters using TLC