Digital Encapsulation of Manufacturing Site Expertise Utilizing Sensing Technology

Seeking to maintain quality at domestic and overseas production sites, Japan's manufacturing industry has recently been looking to improve skills transfer utilizing digital technology. Hitachi has partnered with Daikin Industries on a collaborative creation project to create digital factories. The project has resulted in the development of two digitization technologies that apply image analysis techniques. One is utilized for the digitization of brazing processes used in air conditioner manufacturing. The other is utilized for the digitization of chemical processes used in fluorine-based chemical manufacturing. Currently, Hitachi is identifying the points to monitor when digitizing the expertise of skilled workers, working to create a technology for quantifying expert skills for stabilizing quality, improving productivity, and training staff. In the future, Hitachi plans to create uniform standards for manufacturing processes by integrating information from existing systems. These standards will be implemented at sites throughout the world by using encapsulation to ensure the confidentiality and reusability that expertise requires. They will lead to further improvements in quality and production efficiency.

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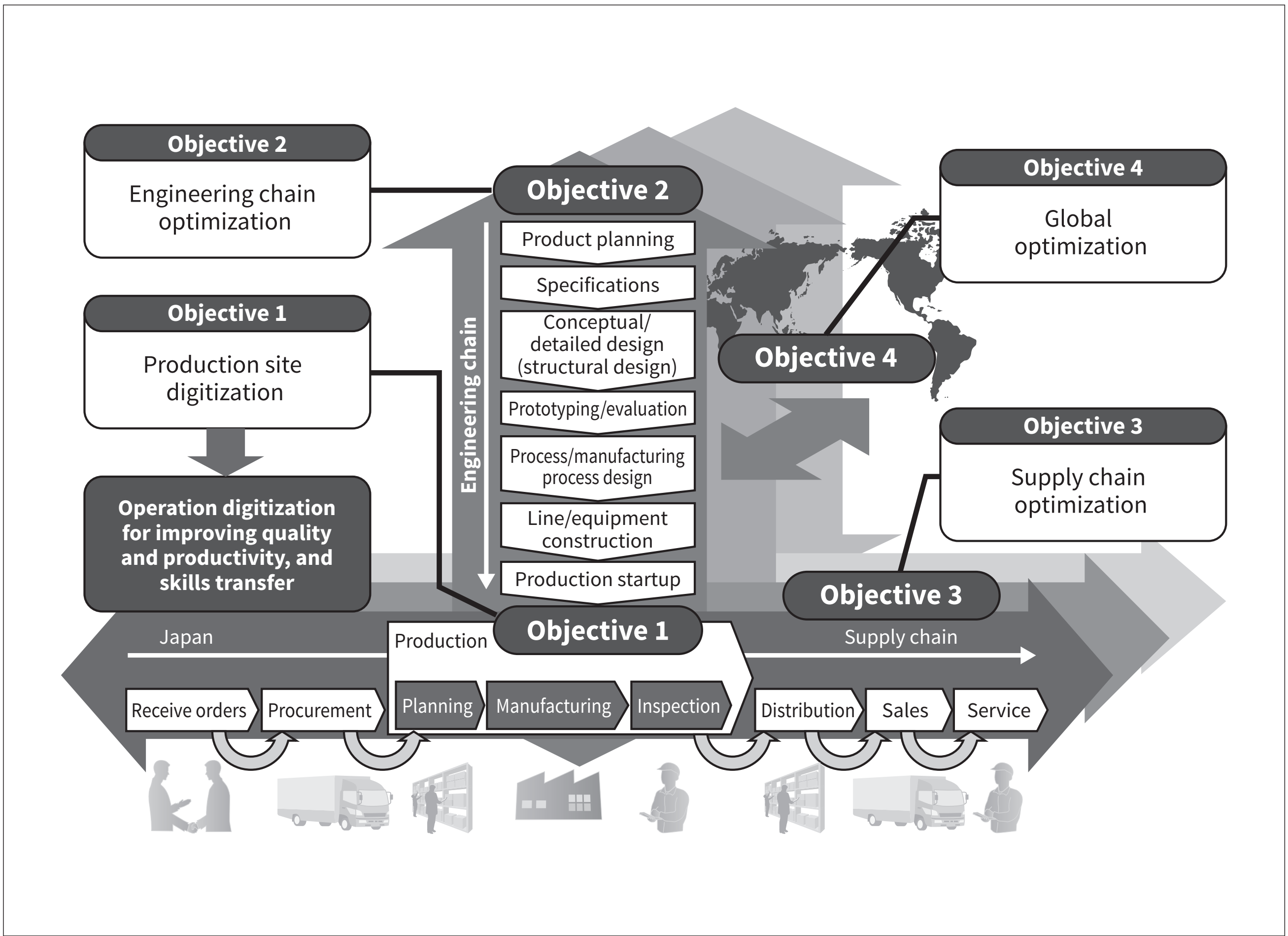
1. Introduction

The 2011 proposal of the Industrie 4.0 concept in Germany marked the start of growing worldwide interest in the use of Internet of Things (IoT) technology and information and communication technology (ICT) in the industrial sector. The Japanese government has responded by proposing the concept, Society 5.0, calling for the utilization of these technologies in manufacturing and various other sectors, seeking to transform the country into an ultra-smart society(1).

The vision for Japan's industries set forth in Society 5.0, 'Connected Industries,' aims to create new added value by interconnecting previously independent elements such as people, objects, machinery, systems, and companies. Examples of expected added value include productivity gains enabled by human-robot collaboration, system-driven staff training, and

Figure 1 — Objectives of the Collaborative Creation Projects
Hitachi's collaborative creation projects are centered on the digitization of production sites, with the aim of expanding them to engineering chain optimization, supply chain optimization, and global optimization.



technological advances and service improvements made possible by interactive use of data spanning multiple organizations(2).

Meanwhile, the intensifying global competition in the manufacturing industry is creating a need for manufacturers to respond rapidly to sudden changes in the market environment. Doing so will require ways of accelerating product development and market releases, as well as improving quality and productivity throughout the entire globalized supply chain.

One of the challenges involved in achieving these aims will be the utilization of systems for skills transfer, and for work relying on human judgment. These systems will be in demand as a way to maintain high levels of quality at domestic and overseas production sites in the face of declining opportunities to transfer manufacturing skills and expertise from experts to young workers as production technologies become increasingly advanced, automated, and outsourced.

2. Aims of Digitizing Manufacturing Site Expertise

2. 1 Background of Collaborative Creation Projects

Since 2015, Hitachi, Ltd. has partnered with chemical manufacturer Daicel Corporation on a collaborative creation project that uses cameras as a new method of sensing. The project aims to improve quality and productivity by acquiring 3M information* from manufacturing sites using image analysis techniques, and integrating it with manufacturing results managed by conventional manufacturing execution systems (MES)(3).

Since 2016, Hitachi has partnered with Daikin Industries, Ltd. on a collaborative creation project

* 3M information (from "man, machine, and material," the factors of production) is Hitachi's term for information relating to personnel, facilities, and materials.

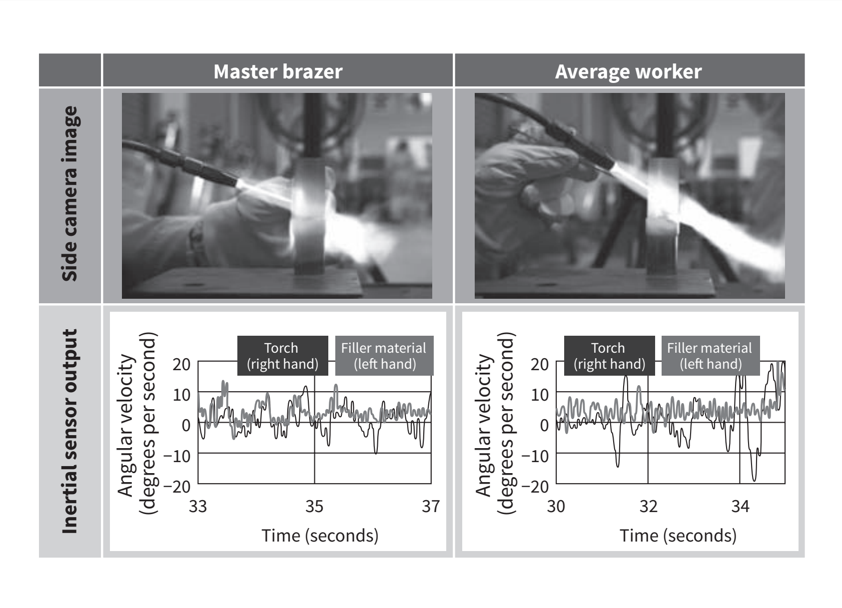


Figure 2 — Comparison of Worker Performance Using Cameras and Inertial Sensors
The work performance of master brazers and average workers can be compared using video and feature values.

that aims to use similar image analysis techniques along with manufacturing site expertise to train staff, and enable uniform quality and better productivity at production sites around the world.

2. 2
Objectives of the Collaborative Creation Projects

To achieve the benefits described above, the four objectives below have been set for the collaborative creation projects (see **Figure 1**).

(1) Use production site digitization (a central element of the manufacturing industry) to improve quality and productivity, and to transfer skills.
(2) Accelerate product development and market releases by optimizing the engineering chain from product development to production startup.
(3) Flexibly respond to changes in the market environment and improve management efficiency by optimizing the supply chain from suppliers to customers.
(4) Apply global optimization to objectives (1) through (3) above.

Daikin and Hitachi selected two manufacturing sites where there are processes it deemed likely to benefit from digitization for improving quality and transferring expert skills, Daikin's Shiga Plant (Kusatsu, Shiga prefecture), which performs air conditioner brazing processes, and Daikin's Yodogawa Plant (Settsu, Osaka prefecture), which performs fluorine-based chemical processes. Daikin and Hitachi have been analyzing manufacturing data from both processes in terms of the "man, machine, and material" (3M) factors of production and the "methods" (M) unique to skilled technicians, and have been conducting studies and demonstration testing on the digitization of manufacturing sites (physical parameters and work operations).

The next section presents the work being done to enable skills transfer and improvements in quality and productivity by digitizing manufacturing sites.

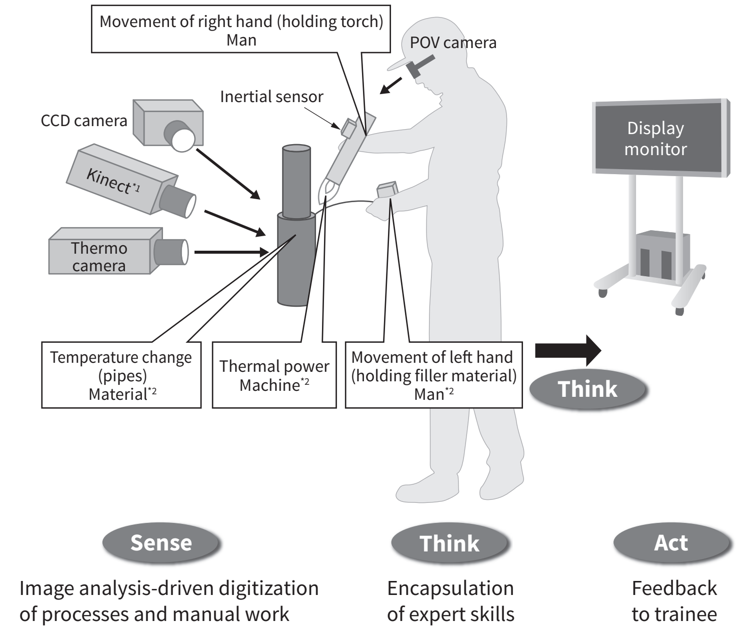
3. Digitizing Brazing Work Operations to Enable Skills Transfer

The brazing process studied for this collaborative creation project is used to join pipes by preheating the joint with a torch and then applying filler material. Air conditioners with poorly brazed joints can leak coolant, causing equipment performance drops or failures. By digitizing brazing skills, the project aims to enable a high degree of leveling of brazing skills and education levels among workers at production sites worldwide. It seeks to maintain and improve the quality of the brazing processes that play a crucial role when manufacturing air conditioners.

3. 1
Brazing Work Sensing

The expert skills and expertise that underpin brazing quality were digitized using sensing equipment such

Figure 3 — Measurement Camera Positions and Brazing Work Feature Values
Digitization using sensing technology can help workers learn brazing skills and increase their skill level.



CCD: charge-coupled device POV: point-of-view
*1 Kinect is a trademark or registered trademark of Microsoft Corporation in the United States and/or other countries.
*2 3M (from "man, machine, and material," the three factors of production) information relating to personnel, facilities, and materials.

as cameras, inertial sensors, and range imaging cameras. Brazing requires skillful operation of a torch to ensure that enough filler material flows into the gap between the pipes. The aim is to create a temperature distribution in the pipes that will encourage the proper flow of filler material. The torch is then used to maintain the temperature distribution while supplying the filler material where needed. Flame height is one of the key parameters for creating the proper temperature distribution during the preheating process.

A comparison of the work performance of master brazers and average workers revealed that average workers tend to use a higher flame, which results in overheating of the pipes. Measurements of the angular velocity of the torch (in the right hand) and filler material (in the left hand) showed that master brazers work with the torch and filler material in a connected manner to prevent heating the material directly (see **Figure 2**). In contrast, no connection between the torch and filler material was found for average workers, providing identification of a skill unique to master brazers that is used to achieve stable brazing quality.

3. 2 Brazing Skill Training Assistance System

Daikin and Hitachi selected 14 feature values related to brazing quality by comparing the work performance data of master brazers and average workers. These feature values were classified into torch operations, filler material supply operations, and pipe states. By measuring the feature values using multiple cameras and sensors, it developed a training system used to teach brazing work (see **Figure 3**).

This system records brazing work using cameras and sensors placed around the trainee. Trainees can check their performance from video and from feature values obtained by image analysis. By quantitatively comparing their own work performance against a standard performance model created using measurement data from master brazers, trainees can understand how their own performance deviates from the ideal, enabling efficient training. In the future, Hitachi expects to share the training data on the cloud worldwide to evaluate and manage brazing skill levels at production sites. Training was previously done in a qualitative manner. The new system gives trainees a more efficient training method and clear training targets, while eliminating trainer staff shortages.

By using sensing technology to digitize master skills, the system will help transfer brazing work skills and maintain and improve quality.

4. Digitization of Chemical Processes to Ensure Quality Stabilization

4. 1 Standardizing Evaluation Criteria for Manual Work Done

Since it is difficult to systematize manufacturing processes in small chemical plants using technology such as distributed control systems (DCS), most of the work is done manually. Ensuring the stability of quality is therefore difficult since process data is managed primarily by workers performing fixed point management and entering log records, and inspection results can vary for unknown reasons even when manufacturing conditions are identical. Monitoring manufacturing processes more frequently leads to increased work time and impedes productivity improvements.

Hitachi is working with Daikin on using image analysis to improve the visualization of fluorine-based chemical manufacturing processes using lab flasks. Demonstration testing is being done to convert lab flask state changes during these processes into digital data. **Figure 4** shows an overview of this work. Fixed point management was previously done by evaluating states visually. However, enabling consecutive point management with digitization will enable the visualization of product quality utilizing image analysis and standardized evaluation criteria for manual work without affecting the equipment or workers. Several other benefits can also be expected. Quality problems can be reduced by using digitized data to report problems to workers in a timely manner. Standard operating procedures (SOPs) can be improved using quality analysis combining production results with inspection data. And, quality can be stabilized through feedback to process development.

4. 2 Image Analysis Techniques for Digitization

To develop image analysis techniques through demonstration testing, Hitachi studied the image analysis logic that was best suited to manufacturing site conditions by identifying the site issues and processes to monitor when applying the technology to fluorine-based chemical manufacturing processes using lab flasks. Hitachi is now working on collaborative creation activities aimed at developing a platform for image analysis integration that will enable digitization by combining modules as needed for the processes involved. Using cameras, the conditions of chemical reactions (such as liquid color, viscosity, and foaming) and equipment operation parameters (such as temperature and speed) that were previously monitored

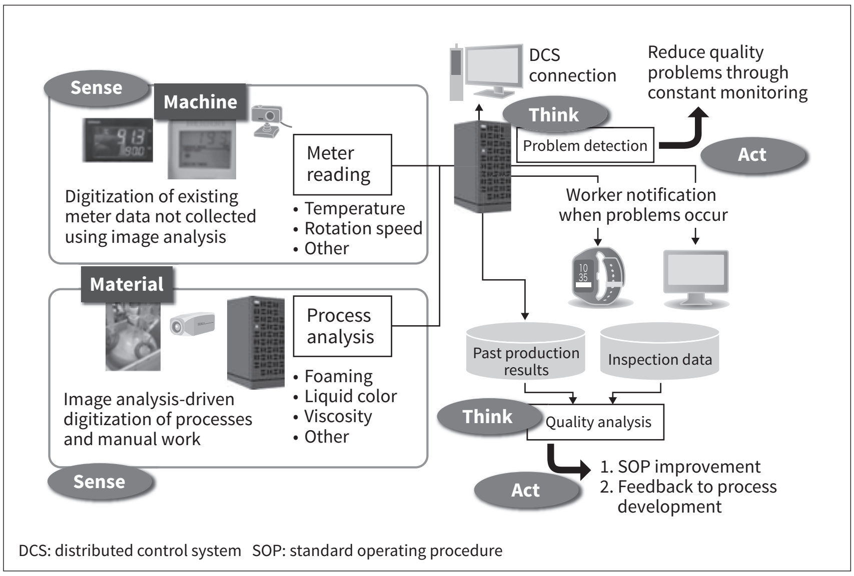
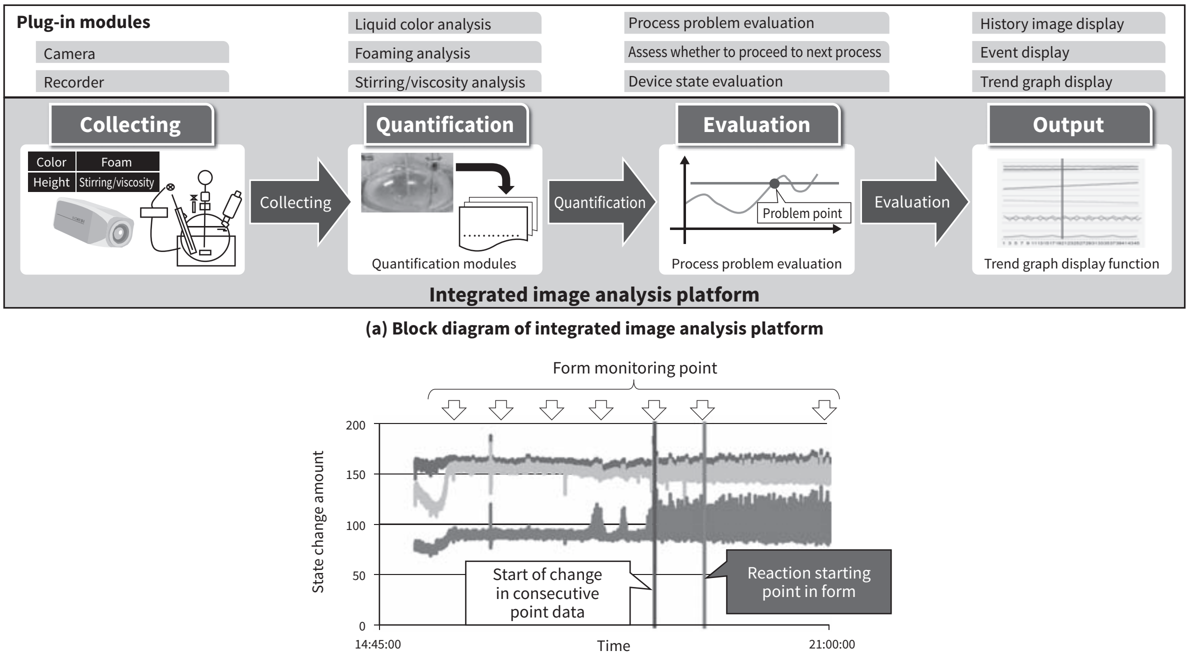


Figure 4 — Digitization Concept

The digitization of process data helps quality transparency and stability by enabling consecutive point management.

Figure 5 — Block Diagram of Image Analysis System and a Digitization Example
Tendencies that previously could not be identified by eye alone can now be identified using digitization done by combining modules tailored to the processes being studied.



(a) Block diagram of integrated image analysis platform

(b) Consecutive point data generated for fluorine-based chemical (example)

by relying on the individual judgments of workers can be collected and digitized in a time series. These data can be managed and standardized as data series [see **Figure 5 (a)**].

When digitizing reaction conditions, color information can be directly measured by a camera, but liquid surface height and foam volume cannot. Therefore, Hitachi worked on determining which physical parameters that are visible in images can be measured as alternatives.

(1) Liquid surface height

Since the liquid surface rotates, it is possible to extract the liquid surface region using motion detection. Lab flasks are round, so the position of the center of the extracted liquid surface in an image indicates the liquid surface height.

(2) Foam volume

Foam contains a large amount of air and appears white in images due to the innumerable diffused reflections that occur inside. The quantity of white regions in the detection area is thought to be proportional to the foam volume.

Figure 5 (b) shows an example of the digitization result for a manufacturing process using the image analysis technique developed through basic demonstration testing. By acquiring data consecutively, Hitachi succeeded in identifying the starting points of changes that could not have been identified by fixed point management.

In the future, Hitachi will work on applying the technology to similar lines and other equipment while improving and enhancing the accuracy of the analysis functions.

5. Conclusions

This article has presented Hitachi's work on the use of image analysis techniques and other sensing techniques to improve quality and productivity in the manufacturing industry, and for transferring skills. The development of two technologies for a collaborative creation project with Daikin was presented as examples. One of these technologies involved the digitization of expert skills used in air conditioner brazing work. The other involved the digitization of evaluation criteria for manual work in fluorine-based chemical manufacturing processes.

The analysis techniques discussed in this article are mainly techniques for the digitization of processes at manufacturing sites. The data obtained using these techniques and existing systems such as DCSs can be integrated and encapsulated along with methods of using data such as skill evaluations and automated control. As a result, reusability can be increased by improving the effectiveness of skills training and enabling expertise-driven automated production. The confidentiality that expertise requires can also be increased at the same time. In the future, it will be possible to implement this digital encapsulation of manufacturing expertise around the world in the form of uniform standards of work, which will lead to the leveling of quality at a high standard.

Through further growth and market penetration, IoT technology and ICT are expected to bring various changes to the manufacturing industry. For example, artificial intelligence (AI) will enable optimum transport planning. Autonomous driving vehicles will enable more advanced supply chains. Robots will eliminate the need for warehouse work done by humans. Predictive diagnostics will increase maintenance efficiency. Big data analysis will be used to identify factors that affect quality. Demand forecasts will be created from product usage data in the market, and new services will provide new value to users.

By creating image analysis techniques as one of the solution cores of the Lumada IoT platform, Hitachi will bring this technology to a wide range of sites and users. It will continue working to enable site data and other information obtained with these techniques to be used for improving sites and for bringing value to other supply chain-, and engineering chain-related departments, as well as to management and the market.

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