Featured Articles

Development of IT-driven Power Plant Engineering Work Support Systems

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OVERVIEW: Rapid and detailed estimates for planning installation or replacement of equipment, or maintenance work are key requirements for meeting the demands for greater power plant reliability and lower costs, and for maintaining safe and secure operation. Hitachi has addressed these demands by developing technology driven by the latest IT. When replacing equipment at complex power plants with high equipment density, the existing state of the installation locations and transportation routes for old and new equipment need to be properly measured. Hitachi has met this need by developing parts recognition technology based on 3D measurement. When decommissioning nuclear power plants, work needs to be done safely and efficiently, minimizing exposure caused by handling of radioactive waste. Hitachi has met this need by developing a technology that applies estimated dose rate to 3D models to enable high-speed calculation of optimal routes for carrying materials in/out. This article provides an overview of these development projects.

INTRODUCTION

SATISFYING the complex web of client requirements and site conditions when constructing a new facility such as a power plant, steel mill, chemical plant or oil refinery requires a wide variety of engineering work. This includes environmental assessment, civil engineering/construction, equipment design, equipment procurement, installation, and trial operation/handover. Plant maintenance also requires advanced and detailed engineering work to diagnose component equipment, machinery, and devices, and to repair/replace them as needed to maintain safe and stable operation. When providing engineering services to clients for new plant construction or maintenance, detailed and rapid estimates of costs and work schedules need to be created. To meet these needs, Hitachi has developed several technologies designed to enable more advanced engineering work through use of the latest information technology (IT).

This article looks at plant maintenance and replacement. Plants of between 30 and 50 years old sometimes only have original design drawings in two dimensions (2D), or have undergone so much maintenance over the years that their plumbing or equipment systems have become unrecognizable from the original drawings. Basing a project plan on the existing state of the plant is an important requirement in these cases.

Hitachi has met this requirement by developing an ‘as-built’ modeling technology based on three-dimensional (3D) measurement and a technology for planning approaches to plant construction/decommissioning based on 3D models (described in the following chapters).

EFFORT TO IMPROVE EFFICIENCY OF SITE STUDIES

Power plant replacement projects consist mainly of removing the items that need to be upgraded, and installing the new equipment. When planning each operation, a key requirement for large plants is to identify the actual state of the surrounding environment to answer questions such as whether there are any obstacles in the transportation routes for removal and installation, or whether reliable connections can be made to existing equipment items. Specifically, the site is surveyed to identify locations to be added or moved, locations that have been transformed by many years of operation, and other site-specific issues. The results of these studies are then used to create

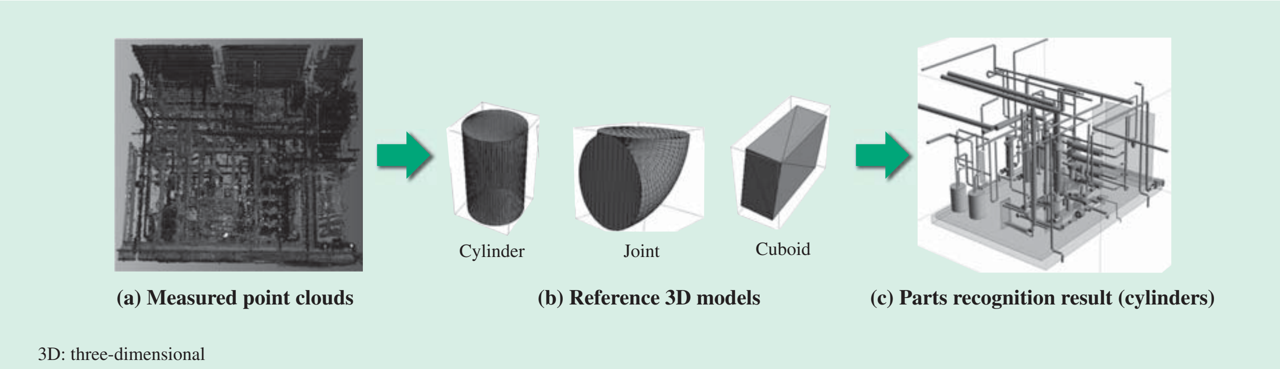


Fig. 1—Parts Recognition from Measured Point Clouds.
(a) Shows measured point clouds for pipe equipment (25 measurement locations, 250 million point clouds). (b) Shows some of the basic-shape reference 3D models (cylinder, joint, and cuboid). (c) Shows an example of cylinders recognized automatically from the measured point clouds.

structural designs and process designs. To increase the efficiency of processes ranging from design to installation, and to eliminate the need for skill in site studies, Hitachi has worked on using 3D measurement by long-distance contact-free laser scanners to enable rapid measurement of existing site conditions.

Laser scanners have recently come into wide use in fields such as civil engineering, construction, and surveying. But measured point clouds contain noise, and since point cloud data is massive, generating as-built models requires extensive manual labor. This chapter discusses technology for recognizing parts from measured point clouds, and reverse engineering technology used to generate data for 3D printing from measured point clouds. These technologies are designed to reduce the lead time from site study to client design proposal.

Technology for As-built Modeling from Measured Point Clouds

Hitachi has developed technology that detects the deviation between a measured point cloud and reference 3D model, and automatically generates an as-built model that reproduces the actual shape[1]. Specifically, the technology involves the following three steps.

First, a preprocess is performed in which the 3D model is transformed into polygons, and the polygons are divided into triangular meshes. The divided triangular mesh connections are then transformed into a graph network model. Finally, network analysis is used to recognize basic shapes such as cylinders, joints and cuboids, and the distance between each recognized basic shape and the measured information is minimized to generate an as-built model.

Hitachi has verified the developed technology using measured point clouds of piping equipment (25 measurement locations, 250 million measured point clouds) and reference 3D models (cylinders, joints, cuboids). The parts recognition processing time was 315 minutes, and the recognition rate was 95%, with 440 out of 463 parts successfully recognized (see Fig. 1).

These study results come from joint research done with the Hungarian Academy of Sciences[1].

Measured Point Cloud-based Data Compensation Technology

To 3D-print a measured point cloud, surface information must be added to it. One method of doing so is to generate triangular meshes. But when the point cloud data volume is large, the computational complexity increases to immense proportions. Another problem is the effect of noise contained in measured point clouds, which can result in generated surface information that does not conform to the original shapes. And, because there are blank spots in the 3D measurements of one location when there are complex irregularities, it is necessary to integrate the point clouds for 3D measurements in multiple locations.

Hitachi has developed technology that uses point clouds measured in 3D with a laser scanner to generate 3D printing data for a plant facility of about 5.1 (W) × 3.3 (H) × 20.0 (D) meters in size. The measured point clouds are a combination of measurement results from 11 locations around the facility, made up of point cloud data of about 1 billion points.

Although combining measured point cloud data from multiple locations can reduce the number of blind spots, acquiring point clouds without any

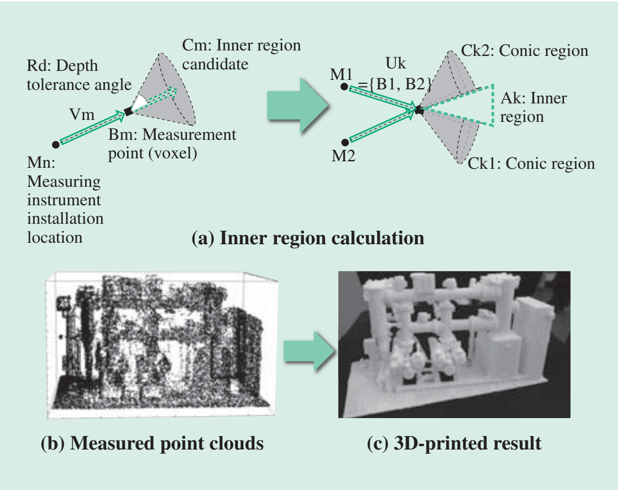


Fig. 2—Measured Point Cloud-based Data Compensation Technology.
(a) The inner regions were calculated using measured point clouds from the locations at which the measuring instruments were installed. The 3D-printed result (c) shows that the technology can compensate for omissions in the measured point clouds (b).

structural omissions whatsoever is difficult in practice. Hitachi has addressed this problem by developing technology that can handle measured point clouds that contain omissions by compensating for the structural discontinuities when generating the 3D printing data.

Specifically, the technology works using the following four steps. First, the point cloud data is transformed into unit lattice (voxel) data of specific dimensions. Only the voxels that contain the set number of point cloud data points are then extracted. For each voxel, the measurement angle is then determined from the position of the laser scanner during 3D measurement, and this measurement angle is used to calculate the inner region of the object [see Fig. 2 (a)]. Finally, the voxels inside the object are compensated for.

3D printing of the measured point clouds for the plant facility demonstrated that this development method can compensate for the data of omitted locations inside of objects [see Fig. 2 (b) and (c)].

Models of the 3D printing results before and after the application of this technology were used to study the locations of structural discontinuities. It was found that the 120 discontinuities that existed before application of the technology were reduced to just 20 discontinuities afterward, demonstrating that the technology could automatically compensate for omissions.

Conventional data compensation processing takes about one month. The usual method is to generate triangular meshes from measured point clouds, visually check parts that vary from the as-built information by taking photographs, and then make revisions manually. Hitachi's 3D print data generation technology has been able to reduce the time required to about seven minutes.

EFFORT TO ENABLE MORE ADVANCED CONSTRUCTION/DECOMMISSIONING PLANNING

Installation Work Planning Simulator

When constructing or replacing substation equipment, a large amount of plant-assembled and plant-inspected equipment items are successively installed at the site. The equipment items are heavy, so they are lifted by crane for transport, positioning, and connection work. These processes require studying the installation sequence and creating work plans after taking into account difficulties in making equipment parts fit each other in three dimensions, and the temporary placement of equipment delivered to the site. It is difficult to visualize with 2D drawings. Besides, the process of planning the installation of substation equipment items requires a lot of experience and specialized knowledge (see Fig. 3). Therefore, Hitachi

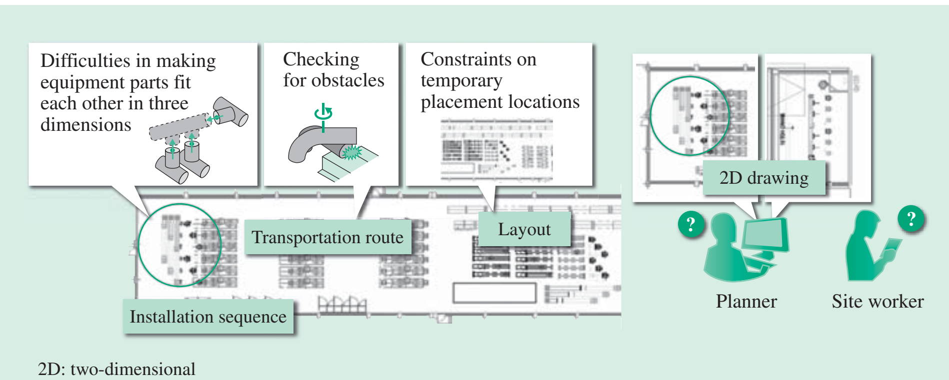


Fig. 3—Installation Work Planning Challenges.
Preliminary studies are required for various cases, such as difficulties in making equipment parts fit each other in three dimensions, obstacles to work operations, and temporary placement layout.

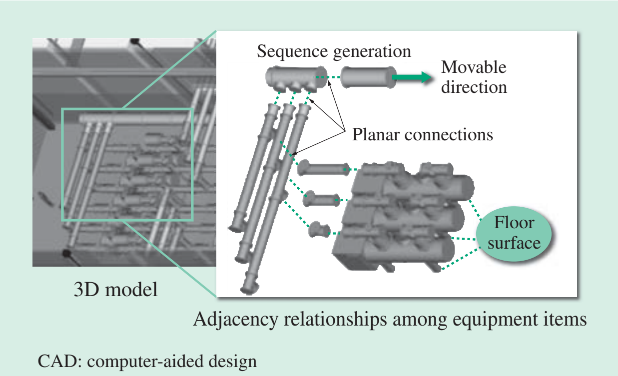


Fig. 4—Automated Generation of Installation Sequence from 3D Model Adjacency Relationships.
The results of analysis of adjacency relationships are used to derive the directions in which the equipment to transport can be disassembled, to derive the disassembly sequence, and to convert this information into an installation sequence.

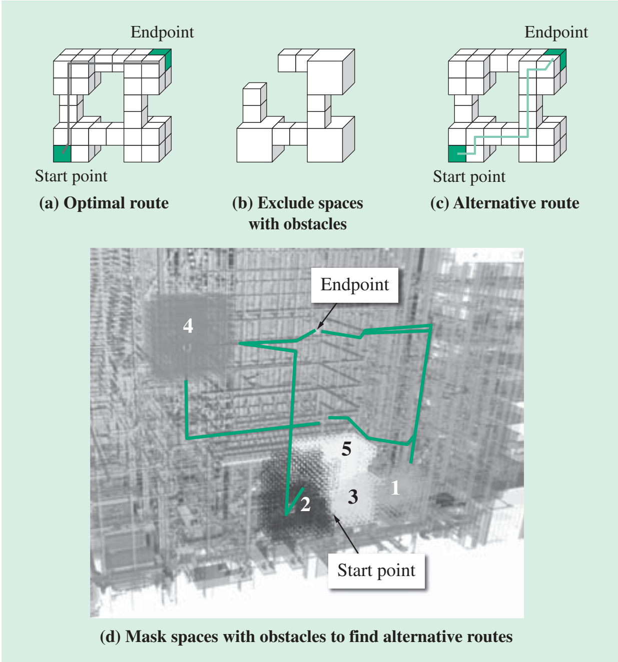


Fig. 5—Method of Suggesting Alternative Routes.
(a) Shows the optimal route. (b) Shows the spaces excluding spaces with obstacles. (c) Shows an alternative route. (d) Shows the obstacle spaces that were excluded for alternative route finding.

has developed technology for generating installation work instructions represented by 3D animations[2].

Specifically, this technology automatically analyzes the geometrical adjacency relationships among equipment items in 3D models, and derives the direction normal to two adjacent surfaces in which disassembly operation is possible. It also uses the layout positions of partially installed or temporarily placed equipment items to detect obstructions on operation routes and to generate the installation sequence (see Fig. 4). The generated sequence is used to create 3D animations showing the site transportation sequence, temporary placement layout, and overhead traveling crane operation. The animations can be used to study the work beforehand, enabling safe, high-quality installation work.

Large Equipment Carry In/out Simulator

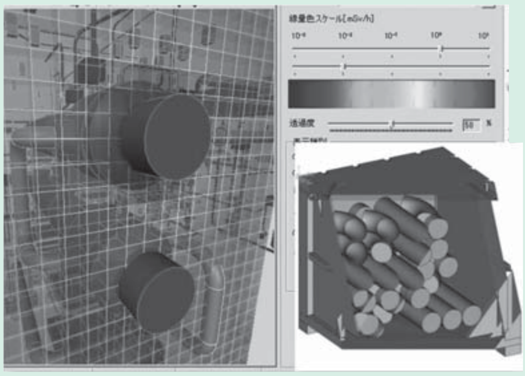
It is difficult to estimate the man-hours required for carrying large equipment in/out of nuclear power plants in maintenance and decommissioning. Therefore, it becomes one of the important factors that cause schedule delays. To protect from radiation exposure, nuclear reactor buildings have complex and cramped spaces. Besides that, the location differential between computer-aided design (CAD) models and real buildings can result in unexpected collisions when carrying equipment in/out. To overcome these issues, Hitachi has developed an alternative route finding method that can flexibly adapt to the real site situation[3].

Fig. 5 illustrates the method developed to find some alternative routes. First, a 3D space with building facets is finely divided into cuboids. Dijkstra's algorithm is then used to find the optimal route passing through cuboids not containing building facets, having the fewest number of turns, and with the most spare room. If there are any obstacles in the real building along the calculated optimal route, then the respective cuboids located on the obstacle are deleted. Then, another optimal route is searched for as an alternative.

The locations of obstacles are acquired from point cloud data measured at the real building over the Internet. A high-speed route finding technique is required to enable alternative route suggestions to be fed back to the site immediately. Facet data of plant buildings can be as much as 10 Gbyte. Developed technology is implemented using parallel computing on a graphics processing unit (GPU), achieving a high processing speed. It can output one route in 1 minute or less, which is about 200 times faster than a single-core CPU.

Automation of Large-scale Waste Quantity Estimation

To calculate the quantity of radioactive waste generated when decommissioning nuclear power plants, Hitachi has used 3D models to create a database for spatial distributions of dose rate. Spatial dose rates are calculated using the Particle and Heavy Ion Transport



CAD: computer-aided design

Fig. 6—Example of Spatial Dose Rates and Visual Representation of Waste Containers.
The spatial dose rate calculation results are loaded into a 3D CAD system, and a visual representation of the work environment is created. A model is created to represent the state of the cut waste items stored in the containers.

Code System (PHITS)[4] in the database for later use. Then, intelligent 3D models are created using a CAD system to create a visual representation of the calculated doses, creating a function for filtering the display to show spatial ranges with doses rates above a specific level[5].

Fig. 6 shows the spatial dose rates and results for storage of cut pipes in a container. The CAD system is used to create a visual representation of the spatial dose rate calculation results, and has shown that it can be used to calculate changes in the number of containers resulting from changes in the dimensions the pipes were cut to. Radioactive waste quantities that have previously been calculated by weight can now also be calculated by volume or number of containers. Waste that has a high radioactivity level is managed by burying it underground for 300 years. By fitting waste items with tags for individual item management and dosimeters for measuring radioactivity near containers, waste can be managed for long periods using the Internet of things (IoT).

CONCLUSIONS

This article has looked at some of the plant maintenance and replacement technologies Hitachi has developed that are driven by the latest IT. These technologies are used for reverse engineering plant construction in conformance with site surveys, and for preliminary engineering done for construction work using plant models. These technologies are now being applied to thermal power plants in other countries, and trial use has started for substation replacement projects in Japan. For nuclear plant decommissioning applications, Hitachi has started detailed studies with engineering work using specific plant data. As IT functions become more advanced, recognizing worker behaviors in addition to objects will become practical, and it will be important to manage the progress of complex maintenance/replacement projects in realtime with IT systems. These advances will enable higher plant utilization rates and longer equipment life, enabling highly efficient construction and maintenance of safe and reliable social infrastructure platforms. Hitachi will continue to develop technologies to meet this objective.

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