Applications of ICT to Robot Welding System

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In recent years there has been a rise in expectations for the improvement of the productivity of robot welding systems using information and communication technology (ICT). To meet these customer needs, Kobe Steel has developed a 3D-CAD link system that retrieves the data of workpieces from the design department and automatically detects welding lines to create a robot program. This has eliminated the need for customers to teach robots and has greatly improved their productivity. The company also provides a production monitoring software, called AP-SUPPORT™. This software has the capability of automatically collecting production data for the welding robot system and outputting reports on production results, thus contributing to the improvement of productivity at customers' sites.

Introduction

With the advancement of information and communication technology (ICT), the Industrie 4.0 and Internet of Things (IoT), advocated by Germany and the U.S., respectively, are changing production fields drastically. ICT has begun to be widely used for the machines and equipment used in welding processes, which require productivity improvement.

Especially in recent years, there has been a strong demand to improve the productivity of high-mix, low-volume products with complicated shapes, in which higher production efficiency is required as a whole system by closely combining the design section with production sites.

This paper explains the functions of the welding robot system based on the ICT of Kobe Steel and the approach of improving productivity using them.

1. Significance and challenges of welding systems in product lifecycle management (PLM)

Product lifecycle management (hereinafter referred to as "PLM") is the process of uniformly managing product-related information throughout the product lifecycle, including product design, production, maintenance, disposal, and recycling, on the basis of ICT for the purpose of maximizing revenue. A system has been proposed for PLM, in which 3-dimensional CAD (hereinafter referred to as "3D-CAD") is introduced as a designing tool to convert product data into digital data such that the data is uniformly managed from the birth to the disposal of each product (**Fig. 1**).

Productivity improvement using 3D-CAD data is also covered by i-Construction, i-Bridge, and i-Shipping promoted by the Ministry of Land, Infrastructure, Transport and Tourism, Japan[1] and is believed to play an important role in the vertical integration of PLM. In the field of architecture, building information modeling (BIM) has been proposed to realize workflows including procurement, design, and production.

For the vertical integration of production by PLM, an automatic linkage between design information and production command is indispensable. It is also essential to collect information from the machines at the production work site and to feed it back to production scheduling, higher-level designing, procurement, and planning.

However, for the production of steel frames for ships, construction machinery, high-rise buildings, etc., which involves the welding of thick steel plates, it is not easy to generate the operating commands for welding robots from 3D-CAD data. The welding of thick steel plates involves determining the welding layer pattern, welding conditions, and torch electrode manipulation, which requires the know-how of welding itself, robot operation, the positioning of welding targets, etc.[2] Moreover, in addition to the welding current, voltage, and operation status of the welding robot system, the operation records must include the amount of spatter and/or fume and the conditions at the time of abnormal stopping of the robot.

A Kobe Steel welding robot system solving the problem of vertical integration of production includes a CAD link system for generating robot

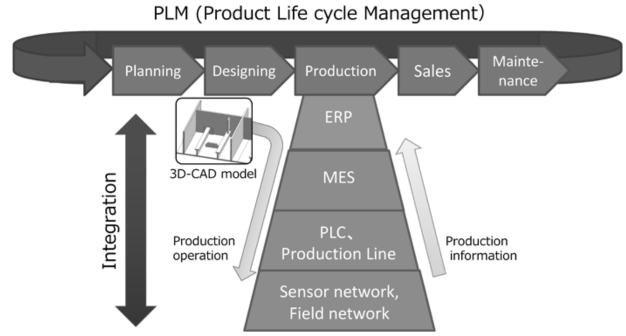

Fig. 1 Vertical integration of production and PLM mainly based on 3D-CAD

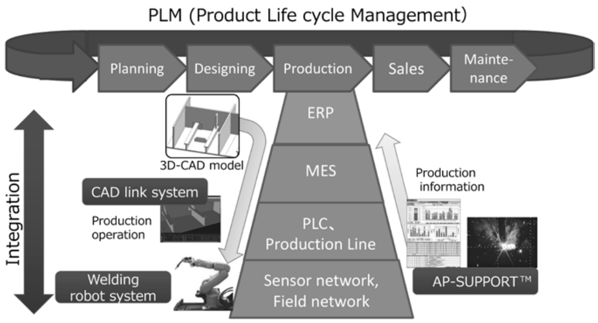

Fig. 2 Significance of welding robot system in PLM

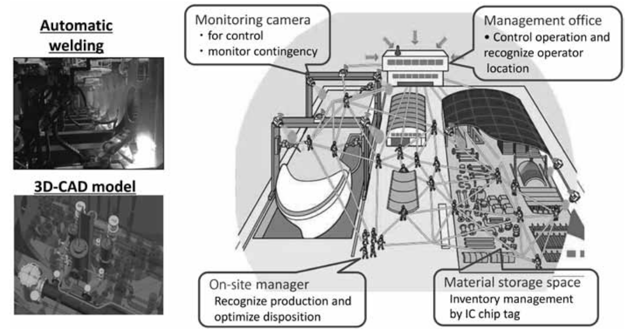

Fig. 3 Productivity improvement of shipbuilding using ICT[4)]

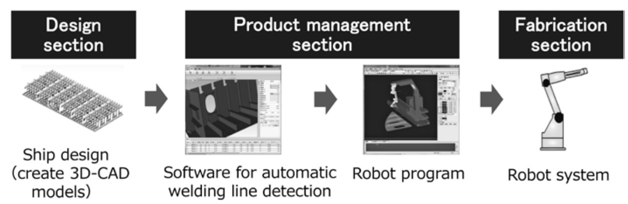

Fig. 4 Automatic generation of robot program from 3D-CAD model

operation commands from 3D-CAD data, and the AP-SUPPORT™ Note 1) that records and reports the operational status of each robot (**Fig. 2**). It also comprises a camera function that can record video pictures in conjunction with the AP-SUPPORT™.

2. 3D-CAD link system

In Japan, the aged population is increasing rapidly, and there has been a remarkable decline in the work force. Against that backdrop, for the sake of its own survival, the shipbuilding industry, which requires a strategic shift to high-mix, low-volume production,[3)] is also promoting automation and labor saving in its production processes. In 2016 the Ministry of Land, Infrastructure, Transport, and Tourism launched a project called "i-Shipping" to improve marine productivity (**Fig. 3**[4)]).[5)] This project promotes the 3D-CAD and automatic welding machines for use in improving shipbuilding productivity. Hence, Kobe Steel has developed a CAD link system for the assembly process of shipbuilding.

2.1 Outline of CAD link system for shipbuilding

The CAD link system provided by Kobe Steel for shipbuilding retrieves 3-D model files prepared by the designing department and performs the coordinate matching of the data. The coordinates system of CAD can be different from that of a robot actually performing welding, depending on the part of the ship. Therefore, in order to detect welding coordinates correctly, it is necessary to match both coordinate systems and this conversion is carried out in the system. Next, welding information is automatically extracted, and the information is edited as necessary to prepare teaching programs. Finally, each program is sent to the corresponding robot to complete the preparation for welding (**Fig. 4**).

2.2 Generating robot programs from design data, and welding

The present system automatically identifies each member on the basis of the coordinates and dimensions of the corresponding shape data of the three-dimensional model and detects only the joints to be welded in the assembly process (**Fig. 5**). It also automatically ignores joints where the robot and workpiece interfere and any joints located outside the motion range of the robot. The CAD link system contains the information on welded portions and welding conditions. Therefore, the customers simply prepare geometric information as CAD data, and no additional information is required for the welding. The robot operating commands (robot program) and welding conditions necessary for executing welding are automatically prepared on the basis of the combination of the members for the corresponding joint and the thicknesses of the lower plate and the vertical plate. Recommended data are provided in advance so as to maximize the performance of the welding robot and welding wires, eliminating the need for instructions concerning welding conditions including instructions for leg length and boxing.

The body of the welding robot is mounted on a lightweight robot carrier designed for transportation, is suspended from a crane, and moves among blocks (**Fig. 6**). The robot carrier has an automatic positioning function and is equipped with the machinery necessary for welding, such as a welding wire feeder. For welding, the robot carrier is lowered to a welding position by an operator and located by the automatic positioner, before

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Note 1) AP-SUPPORT is a trademark of Kobe Steel.

the robot operating commands are generated from the 3D-CAD data by the CAD link system and transmitted to the robot to perform welding (**Fig. 7**).

2.3 Application in other fields

The robot welding system for shipbuilding assembly, which comprises a CAD link system that automatically generates optimum welding conditions and robot motions from the 3D-CAD design data, can run multiple robots by itself, greatly contributing to the improvement of productivity at the welding stage. Efforts will continue to further expand the automatic welding technology originating from 3D-CAD to other fields such as steel frames and bridges.

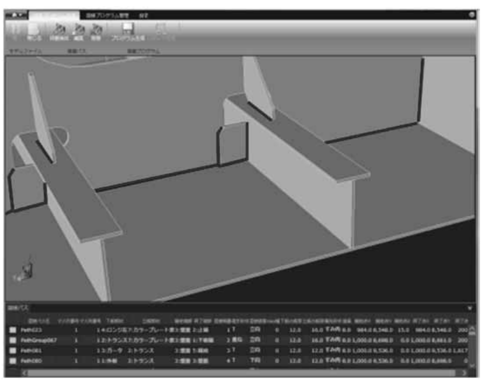

Fig. 5 Automatic detection of welding line from 3D-CAD model

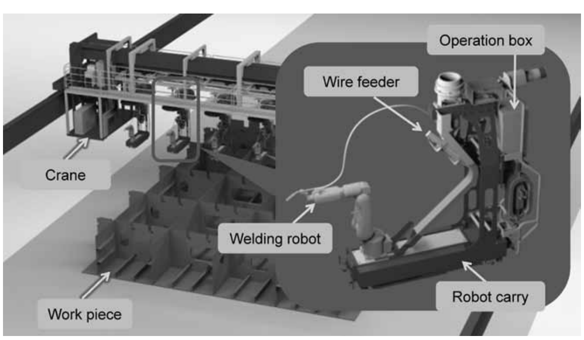

Fig. 6 Assembly welding robot system for shipbuilding

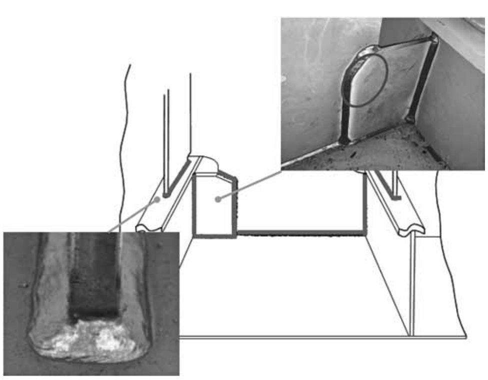

Fig. 7 Welding results of workpieces assembly for shipbuilding

3. Operation management of welding robot system

Realizing stable production by the welding robot system leads to increased production efficiency and facilitated production planning. In the welding of thick steel plates, a significant assembly error may occur due to the large size of the welding objects. Also, there are many factors that inhibit stable operation, such as a temporary stop (a pause due to a mild anomaly) and welding failures, since the welding goes on for a long period of time. When a problem occurs, the accurate understanding of the situations and abundant experience/knowledge are necessary for investigating the cause, and if they are lacking, it takes much time to solve the problem.

Kobe Steel provides software, AP-SUPPORT™, to support stable production. In the company's latest effort, network cameras are installed, and trials are carried out to investigate causes that could not be fully understood from the data alone.

This section describes the outline of AP-SUPPORT™, examples of its application, and the production-monitoring camera system using the network cameras.

3.1 Outline of AP-SUPPORT™

AP-SUPPORT™ is software that runs on personal computers connected with the robot controller via the Ethernet (**Fig. 8**). A large amount of data such as production information and welding information is collected, and the graphs of output and welding data for the production reports are displayed (**Fig. 9**). This has enabled supporting analysis of troubles such as temporary stops and welding failure, as well as the management of production indices such as production volume, takt time, and arc rate, leading to the efficient implementation of production improvement.[6)-9)]

The main data collected by AP-SUPPORT™ is shown in **Table 1**.

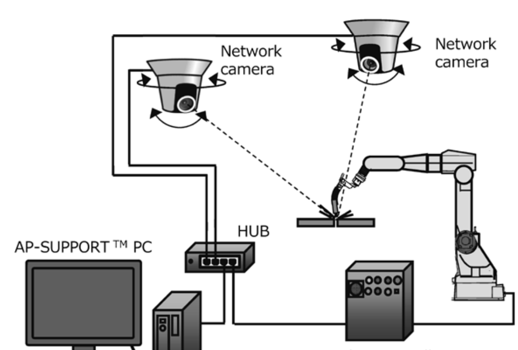

Fig. 8 System configuration

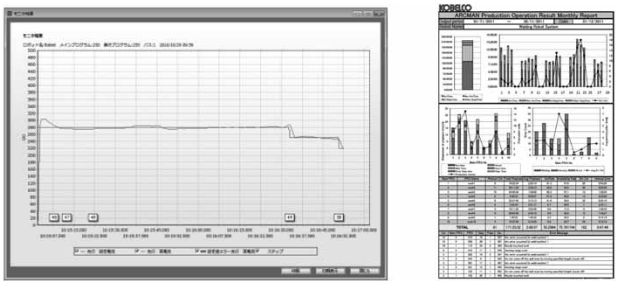

Fig. 9 Function overview of AP-SUPPORT™

Table 1 Production data collected by AP-SUPPORT™

Production information	Welding information
Work data(Program/ Step/Pass)	Welding current
Production start time/ end time	Arc voltage
Welding start time/ end time	Welding speed
Sensing start time/ end time	Weaving width
Sensing retry start time/ end time	Wire feed rate
Welding retry start time/ end time	Wire feed torque
Error stop start time/ end time	Arc tracking adjustment
Wait timer start time/ end time	
Port in out signal ON time / OFF time	
Deviation of the sensing position	
Error type	
Robot position when error occored	
Log of teaching pendant	

3.2 Example of production improvement

Analyzing the data collected by AP-SUPPORT™ allows the determination of the cause of temporary stops and addressing it. **Table 2** shows the results of ranking the locations where touch sensor errors occur frequently and the results of examining the method for dealing with problems based on the situations where errors occur. The cycling of data collection, analysis and correction have yielded an operating ratio improved by 10% or higher in many cases.

It is also possible to check the trend of the amount of sensing correction in order to determine the difference between the actual workpiece and the previously taught program. This can be used for the management of workpiece assembly accuracy (Table 2, **Table 3**). For example, a great variation in the amount of sensing correction indicates poor assembling accuracy in the previous process step. Moreover, when the correction amount is stable and small, the sensing operation itself can be reduced to shorten the takt time.

3.3 Production monitoring camera system

The production monitoring camera system connects a camera mounted on each welding robot system to the robot controller via a personal computer to constantly take photographs of the robot at work (Fig. 8). The positional information is acquired from the robot controller, and this information is used to control the camera direction, advantageously ensuring that the image captures the position of the robot tip (**Fig.10**).

Table 2 Results of analyzing touch sensing deviation

Ranking	1	2	3	4	5	6	7	8	9	10
Program	88	77	89	80	77	85	78	80	90	88
Step	13	6	8	7	11	10	8	5	8	10
Type of sensing	Start	3-D	3-D	3-D	Start	3-D	3-D	3-D	3-D	3-D
Ave deviation[mm]	7.74	7.12	6.81	5.49	5.28	5.1	4.31	4.15	4.04	4.02
Max deviation[mm]	22.16	11.72	27.06	11.28	10.31	12.1	8.67	9.82	21.56	22.44
Min deviation[mm]	5.11	1.01	1.66	1.05	1.12	0.77	1.48	0.15	0.78	0.14
Standard deviation[mm]	1.77	2.06	3.64	1.81	2.13	2.31	1.44	1.96	2.86	3.13

Table 3 Examples of analysis report of robot errors

Error information		Error Messege	Error occurance situation	Improving point (how to avoid the error)
Eror No.	365	Nozzle touched the work.	(Situation)In the switch back welding program、error occurred after changing the tandem welding to single welding. Nozzle of R torch touched the work. (Caused for)Accuracy error between real work and teaching data at the swich back point.	•Correcting the teaching point
Program No.	100			
Step No.	25			
Weld Pass No.	1			
Occurred in	Welding			
Frequency	21%			
Error No.	367	Arc error occurred (in weld section)	(Situation)Error occurred right before the L torch's arc off point. When robot was executing the timer wait operation, L torch touched the work. (Caused for)Accuracy error between real work and teaching data.	•Correcting the teaching point •Insert "Nozzle touch avoid function"command to the program.
Program No.	101			
Step No.	15			
Weld Pass No.	2			
Occurred in	Welding			
Frequency	15%			
Eror No.	445	Sensing range over (touch off)	(Situaion)3 seconds after tandem welding(both RL) starts, L torch touched to work. (Caused for) Accuracy error between real work and teaching data.	•Correcting the teaching point •Insert "Nozzle touch avoid function"command to the program.
Program No.	111			
Step No.	23			
Weld Pass No.	1			
Occurred in	Sensing			
Frequency	10%			
Error No.	367	Arc error occurred (in weld section)	(Situaion)2-3 seconds after tandem welding(both RL) starts. L-torch 2times, R-torch 4 times. (Caused for)contact tip erro from burn-back.wire feed error cause from contact tip	•Check and change the weld start point •Check the wire feed root (torch cable, conduit cable)
Program No.	105			
Step No.	11			
Weld Pass No.	4			
Occurred in	Welding			
Frequency	8%			

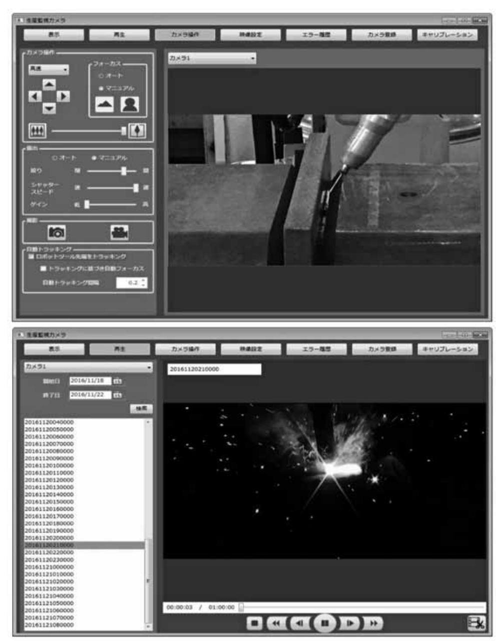

Fig.10 Image captured by production monitoring camera

The camera system also has a function to display currently captured images and to retrieve and display images taken in the past. Furthermore, the cameras are controlled from the PC, making it possible to change the camera direction, zooming, and focusing.

The introduction of this camera system has enabled the recording, together with the imaging, of temporary stops, which hitherto have been known only as sensing errors, and determining the cause of temporary stops in more detail, such as workpiece error, slag and other insulation objects, bent wire, etc. The system can also capture the changes in the amounts of spatter and fume and is expected to be utilized for, among other tasks, the evaluating the stability of welding.

Conclusions

This paper has introduced the function of a welding robot system utilizing ICT. In Japan, the number of welders is envisaged as decreasing with the aging of society and declining birth rates, and the need for improving the productivity of welding robot systems is expected to become even stronger. We will continue to focus on development in the field of welding automation and quality improvement so as to contribute to the improvement of our customers' productivity.

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