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Development of multi welding robot system for sub assembly in shipbuilding

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Abstract: In an effort to increase a productivity of welding process and to reduce the impact to workers from industrial disaster, the research in the field of welding automation is sharply increasing in shipbuilding industry. DSME had developed and successfully applied a welding robot system for grand assembly line in OKPO shipyard in 1997 and has recently developed multi welding robot system for the sub assembly line. This study describes the essential parts of welding automation for the sub assembly process of a hull when using industrial robots. Study includes description of auto detection process of work-pieces, off line program (OLP), host control program and high speed welding method.

1. INTRODUCTION

Nowadays, extensive research in the areas of the welding automation are carried out to alternate the high labour expenses, an aging worker and to achieve high quality of welding. Also, the trend of the welding automation in shipbuilding is changing to full automation and robotization from semi automation and a simple mechanization. In general, in order to weld the sub assembly welding process of the hull which takes approximately 16% of the hull welding processes based on the seam lines, thirty five workers who perform welding on several shops are needed. Most of the welding equipments applied to weld a sub assembly line are semi auto type welding machines, so-called auto carriage. By employing auto carriage to perform welding tasks, there are many merits such as simplicity of operation without any special education for workers, a light weight to handle etc. But, due to certain limitations in the functions of auto carriage, it is nearly impossible to perform an auto tracking of the weld line and round welding which constitute a large portion of welding in shipbuilding. Meanwhile, the repetition process of attaching and detaching an auto carriage gives birth to the musculoskeletal diseases for the workers.

Therefore, Daewoo Shipbuilding & Marine Engineering Co., Ltd. (DSME) has developed multi welding robot systems (MWRS) to minimize these problems. In order to develop the MWRS for sub assembly process, fundamental studies were conducted in relation to the specification of the manipulator and the controller to meet the welding requirements of the sub assembly work pieces, vision system to recognize the shape and the position of work pieces, CAD data interface to create work information for work pieces, Off-Line Program (OLP) to generate robot programs, and the control system to operate many robot systems efficiently. Also, in order to improve the productivity, various techniques to increase the welding efficiency were implemented.

2. SUB-COMPONENT ASSEMBLY LINE

2.1 Line Lay-Out

Figure 1 shows the line constitution of the Component Assembly Shop (CAS) of the DSME where the MWRS is installed. Whole works are performed through the process of component input and arrangement, fit-up, welding, repairing and grinding, and output. Components are arranged on the skid stage (8m (W) x 11m (L)) according to the production schedule. And, 100 ~ 180 m of seam lines, depending upon the types and quantities of arranged components, exist on each skid stage. Also, at least 10 times a day, components are moved to next position by skid stage moving within 2 hours span. The MWRS consisting of four robot gantries and four robot manipulators is installed at the welding area.

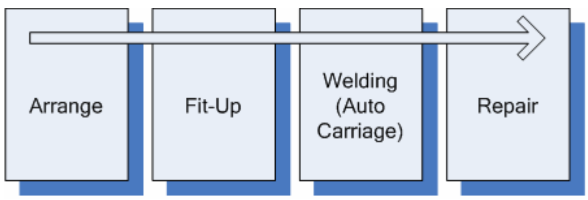

Fig. 1. Component assembly line

2.2 Work pieces and joints

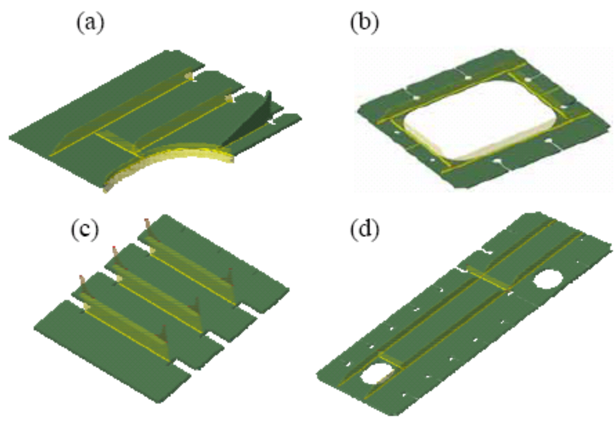

Fig. 2. Examples of work-pieces; (a) 4.5m * 4.2m, (b) 2.7m * 2.4m, (c) 2.5m * 2.4m and, (d) 8.0m * 2.3m

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Figure 2 shows the work pieces that are processed in sub-assembly welding process. Most of the seam lines are defined by the crossing position of the main plates and components. Figure 3 shows the definitions of seam line.

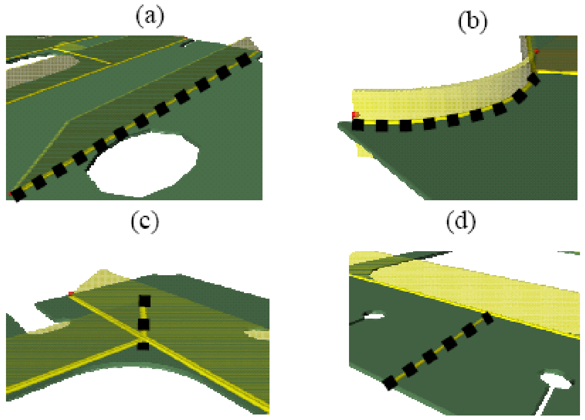

Fig. 3. Definitions of seam line: (a) horizontal linear fillet joint, (b) horizontal linear circular joint, (c) vertical linear fillet joint and, (d) horizontal linear butt joint

3. SUB-ASSEMBLY WELDING ROBOT SYSTEM CONFIGURATION

3.1 Robot system

In sub-assembly process of the hull, work pieces having various types and sizes are arranged according to the worker's discretion. Therefore, in this study, types and sizes of work pieces on sub-assembly process are considered. The results of the nearest teaching point analysis for the possible smooth works of the actual seam line are set as the development standard of a welding robot system. Also, capabilities of the robot works, based on the result of the work piece analysis, are checked. The various working conditions, such as a degree of freedom, type, and working area of robot are simulated.

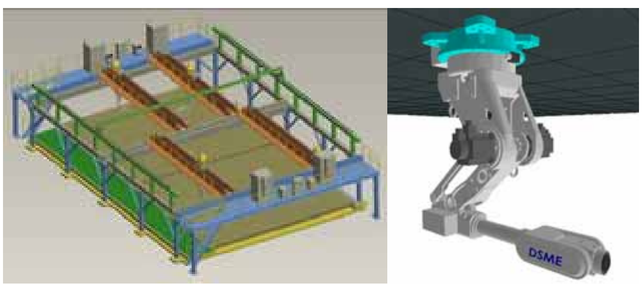

Fig. 4. Robot gantry and manipulator

As a result, DSME has developed the 6-axis articulated robot manipulator with 10kg pay-load and parallel mechanism, and the robot gantry with 21m (L) x 13m (W) x 5.1m (H) 3-axis (X-axis and Y-axis translation and Θ-axis rotation), as shown in Figure 4. Also, each two sets of robot gantries and robot manipulators are installed on the common area so as to perform teamwork operations. And, the specifications of the robot gantry and robot manipulator are shown in Table 1.

Table 1: Specification of Robot system

Items	Specifications
Robot unit	6-axis Articulated, parallel mechanism type 1 Axis: ± 160 deg 2 Axis: + 150 ~ - 90 deg 3 Axis: + 90 ~ - 150 deg 4 Axis: ± 180 deg 5 Axis: ± 135 deg 6 Axis: ± 360 deg
Max reach	1,485 mm
Payload	10 kg
Moving unit	3-axis Gantry type Longitudinal(Y) Axis: 10.5 m Lateral(X) Axis: 6.5 m Rotational(θ)Axis: 400deg(± 200deg)
Welding power	500A inverter type
Sensing function	Touch sensing. Seam line tracking.
Welding torch	Rotating Torch Max. speed: 72 cpm

For the actual welding of seam line, the robot manipulators are moved to the designated teaching points of each seam line by the robot gantries, and the robot manipulators perform the actual welding process. The robot manipulators and the robot gantries move together and perform the work, depending upon the lengths and shapes of seam lines. The position errors and direction errors produced during the actual welding between the actual seam lines and the trajectories of the robot manipulators are compensated by seam tracking function using a rotating torch in real time.

3.2 cad Data interface

3.2 (a) CAD Data generation

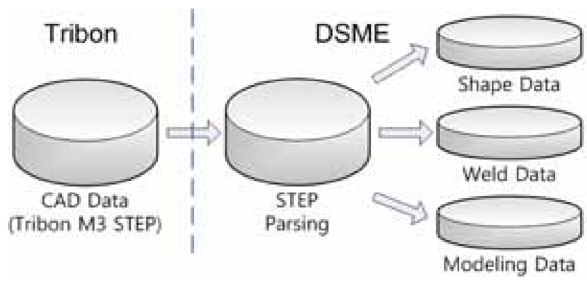

Fig. 5. Procedure of CAD Data Interface

In this study, the CAD data for sub-assembly welding is directly extracted from the TRIBON M3. Figure 6 shows the process to extract the CAD data of the component from the 3-dimensional modelling data of TRIBON design data. Firstly, the base plates, stiffeners, brackets, flanges constituting each work piece are recognized using the STEP-based component modelling data of the corresponding ship and block. And, the crossing line of recognized component and base plate is defined as the seam line. Then, the original work properties based on the component are given to the seam line that is defined at the first time. At this time, the position data of the work piece, which is obtained by the vision system, is a spatial data. Therefore, the extracted 3-dimensional data is used as it is without deformation such as a 2-dimensional projection. And, as shown in Figure 5, the CAD data of the each work piece is defined as the three files.

Figure 6 shows an example of the CAD data. The Shape data is defined as the positions of the edges of both ends at all components constituting the work piece. Also, it is used to decide the shape and arrangement position of work pieces and convert the Weld data to robot working data by the result of the work piece recognition.

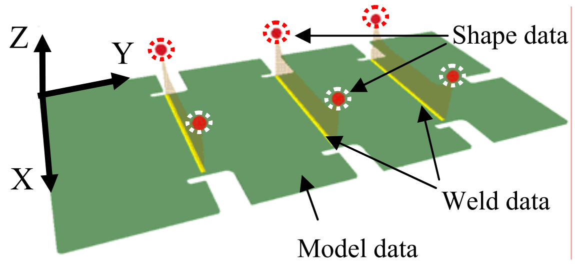

Fig. 6. Example of Shape data, Weld data and VRML data

The Weld data is defined as the information on the seam lines of finally processed components after parsing and analyzing the STEP files. And, the Model data is VRML data of the work piece. It is used for a confirmation of matching result and a simulation of the robot program. Finally, the CAD D/B consisting of the Shape data, the Weld data and the Model data is constructed for each ship and block.

3.2 (b) Interference and collision check

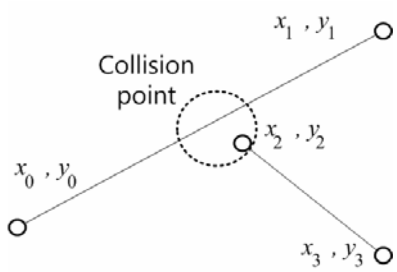

Fig. 7. Collision/Interference area between two lines

Basically, the Weld data includes the basic information such as the positions of both ends of the corresponding seam lines, slopes, heights, diameters, thickness of components, and welding throat length. The information about the types of seam lines and the shapes of starting and ending point belonging to each component is also included in the Weld data. Moreover, the additional information such as angles between components, approach angles, and heights of components, depending upon the types of components is also included. However, it is impossible to produce the information, such as the branched and crossed positions between seam lines in the work pieces, as shown in Figure 7. For the possible moving and workability of the robot, this information must be defined in the Weld data creation.

For that reason, this information must be inputted and changed by the workers. However, these processes are so complicated for workers that the interference check method is developed. When the initial Weld data is defined, the two seam lines are randomly selected among the seam lines, and a parametric equation is defined to compare each of two seam lines. The Eq. 1 is the definition of a basic relation for the interference check method between two lines.

$$\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} t \\ s \end{bmatrix} = \begin{bmatrix} e \\ f \end{bmatrix} \tag{1}$$

Where,

$$a = x_1 - x_0,\ b = x_3 - x_2,\ c = y_1 - y_0,$$

$$d = y_3 - y_2,\ e = x_2 - x_0,\ f = y_2 - y_0$$

Then, the branching point and crossing point of two seam lines are looked up. On the basis of the results of interference check, if needed, each seam line may be divided into separate seam lines, and new information about each divided seam line is generated and changed. This process is performed in the Weld data creation of whole work pieces repeatedly and automatically. Finally, the Weld data for the robot program generation is modified by the result of the interference check.

3.3 Vision System

The work pieces to be worked in this study have diverse sizes and shapes. Moreover, the shape arrangement, positions, and directions of the work pieces on the skid stage are not uniform. Especially, in terms of the structure of the CAS, a possible recognition error caused by the influence of sunlight and a position error of work piece due to vibration while taking a picture cannot be avoided completely. Therefore, in this study, a 3-dimensional work piece recognition system using the photogrammetry method, which does not receive a large influence from the positions and directions of vision cameras and work pieces for photographing and from a external illumination condition, is developed for exclusive sub-assembly block of the hull, as shown in Figure 8.

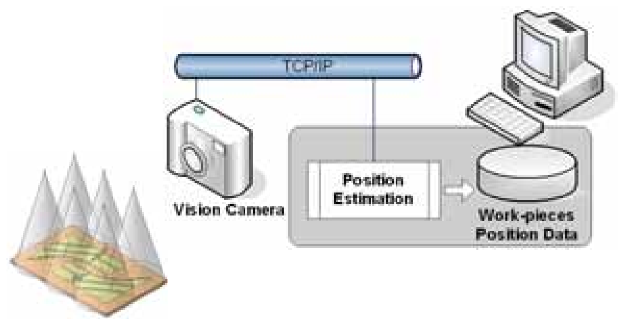

Fig. 8. Concept of vision system

As it is impossible to measure all the work pieces at the same time due to the limited height of the workspace, a camera-moving supportive trolley is installed to perform X-axis and Y-axis translations and Θ -axis rotation on the top of the robot gantry for actual measurement. At the time of actual photographing, the whole skid stage in the welding area is photographed with the trolley moving over 4.5m height on the 16m (W) x 11m (L) skid stage. After completion of photographing, the shapes and positions of the work piece, which are placed on the skid stage, can be calculated by using an exclusive position analysis program, and finally the 3-dimensional result of recognition within 10mm of error can be obtained from the measurement images on world coordinate system.

3.4 Off-Line Program

The OLP generates the robot program to perform a welding work based on the Weld data of each work piece that were captured and calculated by the vision system. It makes use of various Shape and Weld data in the CAD D/B.

3.4 (a) CAD Data Matching

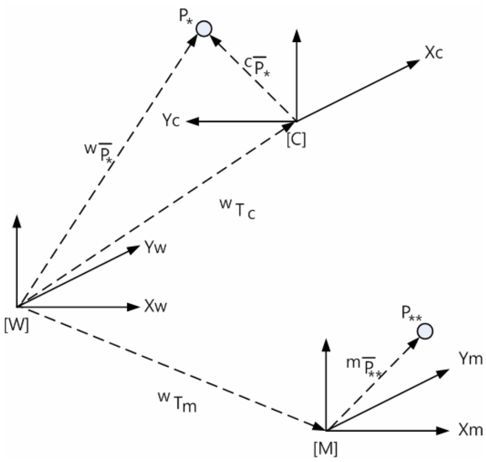

Fig. 9. Transformation between CAD data and work pieces

Firstly, a pattern matching process is performed between the measured results and the Shape data of the CAD D/B. Figure 9 shows the basic relation of pattern matching. Eq. 2 and Eq. 3 define the transformations of the position and orientation between the measured result and the CAD data of the work piece respectively.

$$ {}^{W}\overline{P_{**}} = {}^{W}T_{M} \cdot {}^{M}\overline{P_{**}} = {}^{W}T_{M} \cdot [{}^{W}T_{C}]^{-1} \cdot {}^{W}\overline{P_{*}} \quad (2) $$

$$ {}^{W}T_{P_{**}} = {}^{W}T_{M} \cdot {}^{M}T_{P_{**}} = {}^{W}T_{M} \cdot [{}^{W}T_{C}]^{-1} \cdot {}^{W}T_{P_{*}} \quad (3) $$

The CAD data corresponding to each work piece arranged on the skid stage is automatically screened during the matching. In terms of the properties of the process, many matching results are obtained for each work piece, because many work pieces have very similar sizes and shapes. In this case, the range of look-up subjects may be designated by fixing the ships and blocks, and workers may directly select the corresponding work piece in the CAD D/B. When the screening of work pieces is completed by using the measured position data of the work piece, the Weld data of the each work piece is changed to seam line information of the skid stage according to the world coordinate system.

Actually, work pieces, which are arranged on the skid stage, have the information that cannot be produced in design process, and such information can additionally be defined in production process only. For the convenience in the manufacturing process, actual welding position may be corrected, divided, and/or combined. Sometimes, whole component of the work piece may be excluded from the sub-assembly welding process. Such information of the production process may be corrected and inputted by the workers through additional checking process, if needed.

3.4 (b) Robot Program Generation

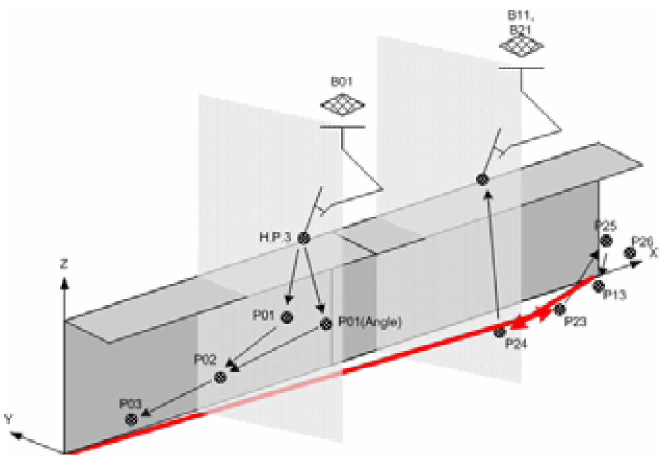

Fig. 10. Definition of teaching points (line type)

The Module-OLP method applied to generate robot programs. Exactly, the each type of seam line constituting the Weld data of work piece is used as the standard in a generation of a robot program. Figure 10 shows the definitions of the teaching points of the robot program for straight seam line that is defined as a module for horizontal linear fillet joint.

The method to define the working sequence and working programs depending upon the shapes, constitutions, and arrangement of components on the work pieces requires repetition or revision for each similar work piece. And, if the new type of component is inputted, or the design is changed, all the parameters must be redefined. Such a process may frequently be required depending upon the properties of work pieces. However, the Module-OLP method does not limit the configuration and the working sequence of work pieces. Moreover, for all of the teaching points in the Module can be defined by the type of seam line, the correction and complement of the robot programs for the change of a design data and work method of work pieces are very easy. Therefore, such troublesome matters can be removed very effectively and easily by the Module-OLP method. As a result, the robot programs are automatically generated regardless of the size, shape, and arranged position of the work piece.

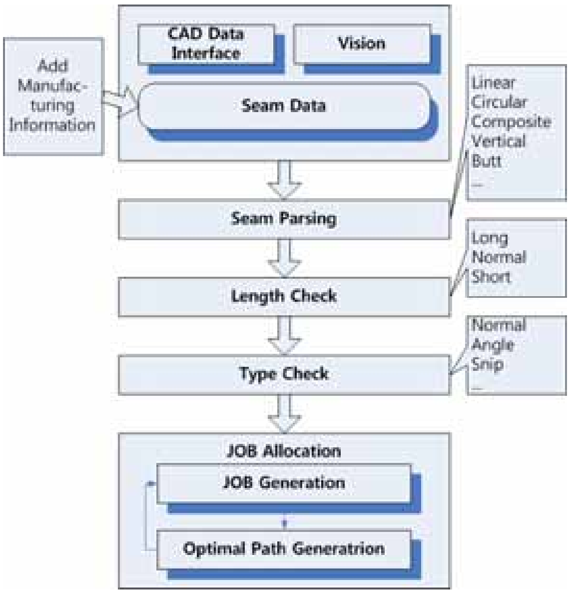

Fig. 11. Flow chart of robot program generation

Figure 11 shows the process of robot program generation. The various information of seam line, based on component, is integrated as single seam line information for the whole stage in the process of robot program generation, and it is changed to the work information of a standard type of a single seam line. Then, robot programs are automatically generated by the defined types of corresponding seam line such as straight line, curve, vertical line, and butt.

According to the structural design of the system, two robot systems share a common work area. Therefore, working programs are automatically allocated to appropriate robot system depending upon the work area and the position of corresponding work. In allocation process, the workloads for all of the robot systems are equalized as much as possible. When program allocation is completed, optimum working sequence and resulted working method of each seam line are automatically decided so as to minimize working time and avoid the interference between two robot systems. After generation of robot programs, if needed, workers can discretionally adjust the working sequence and the allocation of the robot programs. Also, actual working situation and robot working status are informed to workers through the robot system monitoring in real time.

3.5 Central Control Program

The Central control program (CCP) takes charge of complete control of the MWRS. The MWRS consists of independent systems such as vision, OLP, robot controllers, skid stage, etc., as shown in Figure 12. When the skid stage and work pieces are transferred into the work area of the MWRS, the CCP controls the individual and integrated operation to perform the robot programs. The CCP also manages all of the conditions and situations produced during processing of information inputted from outside through operating panel and informing the workers about the current state. All situations generated in relation to the robot system are controlled until all robot programs are terminated.

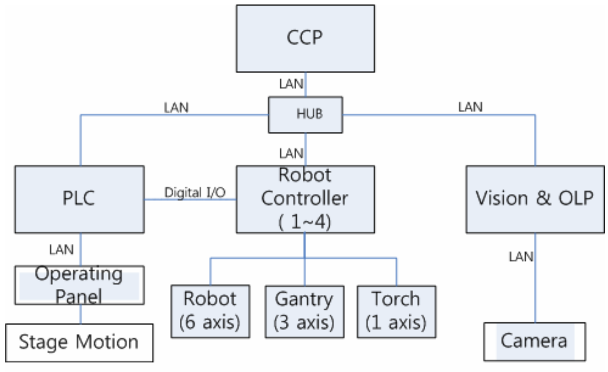

Fig. 12. Control structure of CCP

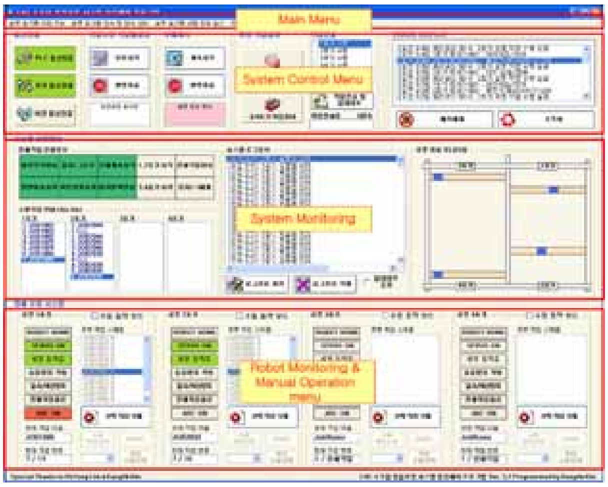

Fig. 13. GUI of the CCP

The CCP consists of the Device control module, the Robot operation module, and the External program module, for efficient operation and control of the MWRS. Figure 13 shows the GUI of the CCP. The Device control module takes charge of operation and monitoring of the apparatus excluding robots such as operating panel, graphic panel, camera, etc. These functions are performed by the input/output signal through PLC. The Robot operation module monitors the robot status related to work progress, such as loading, running, and stopping of work programs for each allocated seam line of each robot system. This module performs the all operations related to robot working. The External program module monitors the process of recognition and position analysis of work pieces, the CAD data matching and checking, and the robot program generation by communicating with OLP system and vision.

3.6 Anti-Collision Program

The Anti-Collision Program (ACP) takes charge of changing of the working sequence to prevent an interference and collision between two robot systems. When performing the robot programs, there are possibilities of interference and collision during operation of two robot systems as they lie on the common area. To prevent such possibilities, the work sequence is decided by prior checking of possible interference and collision of systems during operation by simulation in the process of the robot program generation in the OLP; however, it is almost impossible to check all possible situations of each system and to establish the measures to meet actual operation process. Therefore, to minimize or avoid an exceptional situation that may cause the interference or collision of two robot systems during the operation, the working sequence of each robot system must be adjusted in real time as well as before the starting of the operation.

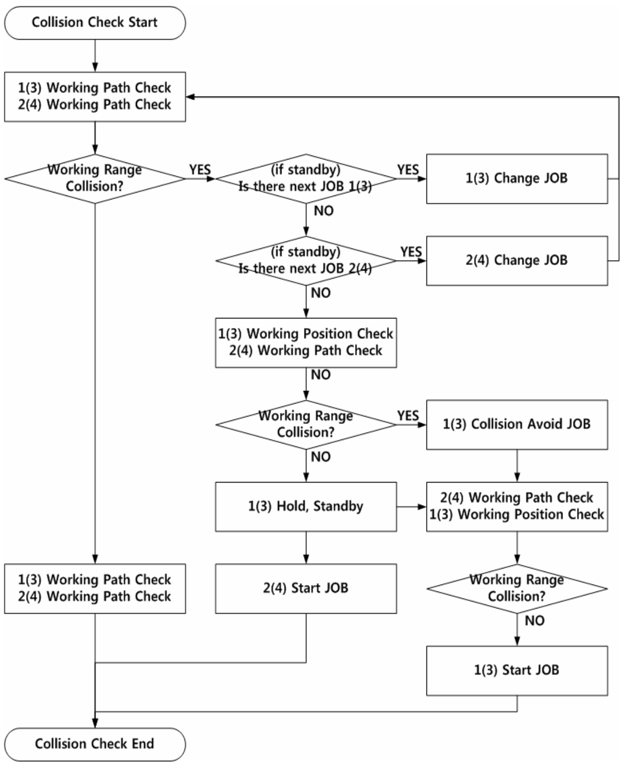

Fig. 14. Interference and collision check process of the ACP

The ACP is developed to be used in this process, and integrated into the CCP. Therefore, the ACP accomplishes efficient work by eluding the possible interference or collision of two robot systems through rescheduling of working sequence by comparing the current position of each robot system with the trajectory of working programs in real time, as shown in Figure 14.

4. IMPLEMENTATION

Figure 15 shows the MWRS and the result of round welding for straight line component by the MWRS. For the high-speed welding and seam tracking, a rotating torch is installed at the end of the manipulator, and the MWRS performs a horizontal fillet welding, with 72cpm welding speed. The position error of the start point between robot manipulator and seam line is compensated by use of touch sensors to correct the welding start point. During welding, the actual positions of seam line and robot program are modified in real time with use of seam tracking function so as to look up the welding end point. As a result, by omitting the detection of the welding end position, which is required before the start of the working, whole arc time of each robot system is increased. Also, by applying the round welding method for the edge of joint, the productivity is improved up to 10%.

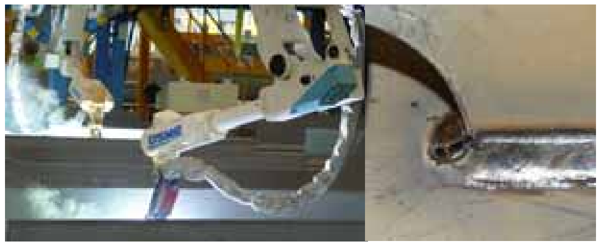

Fig. 15. Picture of the robot manipulator in site and the round welding at the end of the horizontal linear fillet joint

5. CONCLUSIONS

DSME has developed the MWRS for the purpose of improving the productivity of sub-assembly welding process and preventing musculoskeletal diseases of workers; the MWRS is installed at the CAS. Moreover, it is operating well.

Through this study, 3-dimensional recognition method is developed for the work pieces of sub-assembly blocks of the hull. In addition, The CAD D/B of work pieces is constructed with use of design data, and the foundation of the Moduled-OLP for sub-assembly welding is constructed. For the improvement of the productivity, the Anti-Collision program is developed to prevent possible interferences or collisions between two systems and reduce standby times of robot systems. The high-speed welding technique and seam tracking function are also developed to reduce an operation time of each robot program.

DSME is improving the MWRS, based on practical data that obtained through actual operation. And, the MWRS will be applied to similar sub-assembly welding process of DSME in the near future.

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