

## Modularized Control Architecture of an Embedded Controller for Mobile Welding Robot in the Shipyard

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**Abstract:** The present study describes the development of controller hardware and control software for a mobile welding robot, which can move in the transverse and longitudinal directions (Moving Tasks), perform the welding tasks of the U-shaped parts and bracket parts in a double hull structure (Welding Tasks), and detect points of the welding path (Sensing Tasks). Controller hardware consists of a main controller and a welding machine controller. The main controller, which is mounted on the mobile welding robot, consists of a CPU board, a motion controller, and an incremental encoder type AC servo motor driver. The welding machine controller, which is mounted on the welding machine located on the outside of the double hull structure, controls the welding machine. Communication between the two controllers is made via the RS485. Control software consists of 4 layers: *Task Manager*, *Task Planner*, *Actions for Task*, and *Task Executer*. Each Layer consists of modules such as the Action Module, Motion Generator Module, Servo Module, etc. Suitable combinations of modules enable the control software to perform the required tasks. Control software is developed using C programming under QNX Operating System, which is well known to have a reliable hard-realtime performance.

### 1. INTRODUCTION

The present study describes the development of a controller hardware and control software for a mobile welding robot which can move in the transverse and longitudinal directions (Moving Tasks), perform the welding tasks of the U-shaped parts and bracket parts in a double hull structure (Welding Tasks), and detect points of the welding path (Sensing Tasks).

#### 1.1 Fixed-Type Welding Robot

The fixed-type welding robot in the Shipyard normally has 6 axes and works only at a fixed location. The 'DANDY' is a fixed-type welding robot (J. H. Lee *et al.* [1998]) developed by Daewoo Shipbuilding & Marine Engineering (DSME), and it performs welding tasks on a single hull structure at a fixed location. After the work is completed, a crane is used to move the robots to another working location.

#### 1.2 Working Space - Double Hull Structure

Recently, most ships have been built as a double hull structure. The required welding tasks in a double hull

structure are U-shaped parts (Fig. 1.), which are located at the intersection of the transverse web floor and the longitudinal stiffener (Longi).

However, because it is difficult to use a crane to move a robot to another location in a double hull structure, a fixed-type welding robot cannot be used.

#### 1.3. Mobile Welding Robot – 'Rail Runner'

Seoul National University and DSME have been developing a mobile welding robot, called the 'Rail Runner' (RRX). The 2<sup>nd</sup> version of the 'RRX', the 'RRX2', is represented (Kyu-Yeul Lee *et al.* [2007]) and the 3<sup>rd</sup> version of the 'RRX' has been developed. This paper describes the development of control hardware and control software for the 'RRX3'

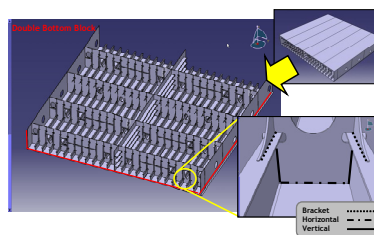


Fig. 1. Welding target in a double hull structure

## 2. PREVIOUS WORKS

The controller for the Fixed Type Welding Robot has been developed (Soo-ho Kim *et al.*[2005]). However, because the controller is some distance from the welding robot, it is not suitable for the mobile welding robot to work in a double hull structure.

The modularising of the unit function of the robot has been studied in order to easily add new hardware such as sensors (Gunhee Kim *et al.*[2003]) and to perform repeatable tasks efficiently (Fabrice R *et al.*[1995]). In addition, 3 Layer Architecture has been studied for real time performance (Sung-Yong Jeon *et al.* [2005], Setfano Caselli *et al.* [2005]). Software architecture based on Hybrid Control Architecture has also been studied (Jindong Liu *et al.*[2006]).

In this study, the control software adapts the Hybrid Control Architecture (Jindong Liu *et al.* [2006]). Furthermore, the mobile welding robot is connected to multiple hardware such as servo motors, sensors, welding machines, etc. Particularly in the case of the industry robot, because it is required to have a high accuracy and to prevent mistakes and problems from arising, the control software is also required to be robust. Therefore, this study develops control software using modularized control architecture. (Gunhee Kim *et al.*[2003], Fabrice R *et al.*[1995])

## 3. WHY AN EMBEDDED CONTROLLER FOR THE MOBILE WELDING ROBOT – ‘RRX3’

In order to perform the Welding Tasks, the welding robot needs to be able to independently move in the longitudinal and transverse directions. In the case of the ‘DANDY’, which is the fixed 6-axis welding robot developed by DSME, a controller is located some distance away from a welding robot. Consequently, a ‘long’ motor power cable and motor encoder cable is required between the controller and the robot, while the gantry crane holds up the weight of the cables. However, in the double hull structure, the ‘RRX3’ is required to drag the cables without the use of the crane. Therefore, the controller is developed as an embedded type in order to minimize the number and the weight of the cables. Figure 2 shows the compositions of the cables for the ‘RRX3’ and the ‘DANDY’.

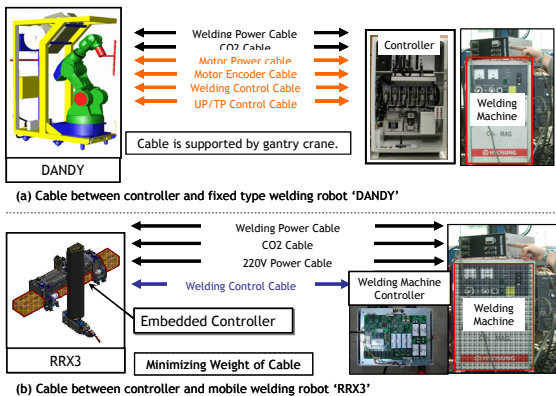


Fig. 2. The cable located between the controller and the welding robot (‘DANDY’, ‘RRX3’)

## 4. MODULARIZED CONTROL ARCHITECTURE OF THE EMBEDDED CONTROLLER FOR THE MOBILE WELDING ROBOT ‘RRX3’

### 4.1 Embedded Controller for the Mobile Welding Robot ‘RRX3’

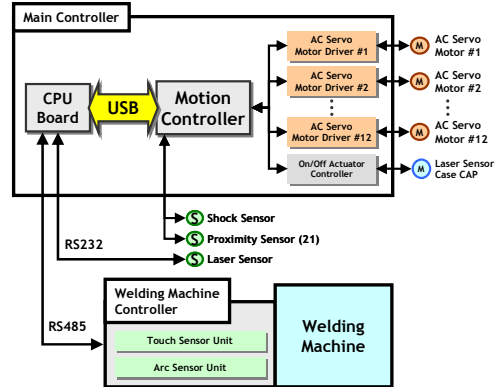


Fig. 3. Configuration of the embedded controller for the mobile welding robot ‘RRX3’

The controller hardware of the mobile welding robot consists of the main controller and the welding machine controller. The main controller is mounted on the ‘RRX3’ and it controls the AC servo motors and the sensory systems (Proximity Sensor, Laser Sensor, and Shock Sensor). The welding machine controller is attached to the welding machine in order to accurately control it (Fig. 3).

#### 4.1.1 Main Controller

If the main controller is some distance away from the robot, then the mobile welding robot needs to drag the ‘long’ motor power and encoder cables. In order to avoid such a situation, the controller is mounted on the bottom of the ‘RRX3’ (Fig. 4).

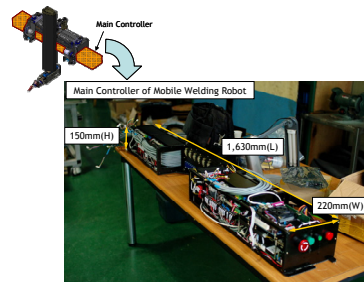


Fig. 4. The main controller for the mobile welding robot ‘RRX3’

The main controller consists of a CPU board, a motion controller (which is able to execute linear interpolation for all 12 axes), and the 12 AC servo motor drivers. The CPU Board is 866LCDM/mITX, which is a commercial product manufactured by KONTRON. It has robot control software that is developed by this study. The motion controller receives commands from the CPU board, and it then controls the 12 AC servo motor drivers. The motion controller and the

AC servo motor drivers are developed by this study. The 'RRX3' has motors manufactured by Panasonic. However, the size of Panasonic's commercial AC servo motor driver is too large to place in the embedded main controller. Therefore, the motion controller and the AC servo motor drivers were developed. The drivers are Incremental type.

4.1.2 Welding Machine Controller

In the case of the 'DANDY', which is a fixed-type welding robot, the main controller and the welding machine are located in close proximity to each other. In this case, there is no limitation for the controller to manipulate the analogue voltage, which is the input and output data type of the welding machine. However, as the length of cable between the main controller and the welding machine increases, the more difficult it becomes for the main controller to correctly manipulate the analogue voltage, due to the effects of the voltage drop and noise. Therefore, in this study, the welding machine controller (Fig. 5), which can control the welding machine, is developed and attached to the welding machine.

The welding machine controller has an arc sensor, which is developed inside by DSME. It can therefore ensure that the welding torch continues to follow the welding path. The intensity of the electric current during welding is in inverse proportion to the distance between the torch and the welding part. The welding machine controller uses this current to calculate the distance between the torch and the welding part and to decide whether the work is successfully accomplished.

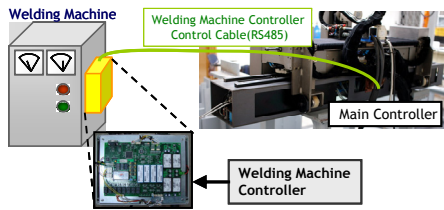


Fig. 5. The connection between the welding machine controller and the main controller of the mobile welding robot 'RRX3'

4.2. Control Software Architecture for mobile welding robot 'RRX3'

The newly developed mobile welding robot performs Moving Tasks and Welding Tasks that require high accuracy (error range: under 0.5mm). In order to control the welding robot that performs these tasks, the 'actions' of the welding robot are defined, and suitable combinations of 'actions' enable the control software to perform various required tasks.

4.2.1. Modularized Control Software Architecture

Control software consists of four layers: *Task Manager*, *Task Planner*, *Actions for Task*, and *Task Executer*

- *Task Manager*: The *Task Manager* manages the task list that is provided by the users, and communicates with the Teaching Pendant (TP).

- *Task Planner*: The *Task Planner* receives tasks from the *Task Manager*. The *Task Planner* then chooses 'actions' in *Actions for Task*.

- *Actions for Task*: *Actions for Task* receives 'actions' from the *Task Planner*. *Actions for Task* then generates the trajectory of the robot by using environmental data and robot status data, which is provided by the *Task Executer*.

- *Task Executer*: The *Task Executer* controls the motion controller and the actuator. It causes the robot to execute the tasks. The *Task Executer* then receives environmental data and robot status data from the sensors.

The tasks, chosen by the *Task Planner*, can be performed through combinations of 'actions' in *Actions for Task*. Furthermore, to easily add new hardware, the unit functions of the *Task Executer* are modularized. Figure 6 is a diagram of the four layers and modules, which compose the control software.

4.2.2 Task Planner

The *Task Planner* performs tasks, which are provided by the *Task Manager*, while combining 'actions' in *Actions for Task*. The functions of the *Task Planner* corresponding to each task are as follows:

a) 'Move in the Transverse Direction' and 'Move in the Longitudinal Direction' (Moving Tasks) The *Task Planner* performs Moving Tasks by combining 'activate sensors' and 'sequential motor control for transverse movement' or combining 'activate sensors' and 'sequential motor control for longitudinal movement' in *Actions for Task*. The physical procedure of moving tasks is shown in the section, '5.1. Example of performing Transverse Moving Task by combining modules' and in '5.2. Example of performing Longitudinal Moving Task by combining modules'.

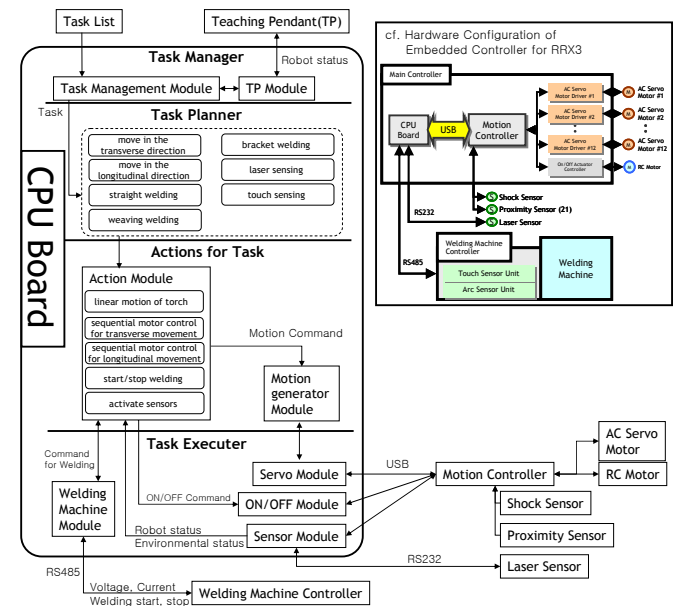


Fig. 6. The four layer architecture and modules of the mobile welding robot 'RRX3'

b) Straight Welding, Weaving Welding and Bracket Welding (Welding Tasks)

The *Task Planner* performs the Straight Welding Task and the Weaving Welding Task by combining the 'linear motion of torch' and 'start/stop welding' tasks. The concrete procedure of Weaving Welding Tasks is shown in the section, '5.3. Example of performing Weaving Welding Task by combining modules'.

c) Laser Sensing and Touch Sensing (Sensing Tasks)

The *Task Planner* performs Sensing Tasks by combining 'activate sensors' and 'linear motion of torch' in *Actions for Task*.

#### 4.2.3. Modules of Actions for Task

*Actions for Task* executes 'actions' that are required to perform various tasks. *Actions for Task* generates the trajectory of the welding torch. At the same time, this layer communicates with the laser sensor, the proximity sensor and the shock sensor in order to receive environmental data, which concerns the existence of the longitudinal stiffener (longi) and the distance between the welding robot and the U-shaped welding part. When the welding robot performs the Welding Tasks, *Actions for Task* starts or stops the welding, while executing other 'actions'.

Similarly, *Actions for Task* has several 'actions', which are performed simultaneously. *Actions for Task* performs required tasks with suitable combinations of these 'actions'. There are 2 types of modules in *Actions for Task*, the Action Module and the Motion Generator Module.

1) Action Module

The *Task Planner* selects suitable 'actions' in the Action Module. The Action Module then transfers the command to other Modules in the *Task Executer*, which correspond to the 'actions' selected by the *Task Planner*. The functions that correspond to each 'action' are as follows:

a) Linear motion of the torch

The action Module transfers the motion command to the Motion Generator Module, and the Motion Generator Module generates the trajectory of the welding torch, and transfers the angle data of each motor to the Servo Module. 'Linear motion of torch' is necessary to perform tasks (Weaving Welding, Bracket Welding, Touch Sensing, etc) that are related to the motion of the welding torch.

b) Sequential motor control for transverse movement, sequential motor control for longitudinal movement

The Action Module controls the Servo Module to perform Moving Tasks, using environmental data from the Sensor Module. 'Sequential motor control for transverse movement' and 'sequential motor control for longitudinal movement' are necessary in performing tasks (Move in the Transverse Direction, Move in the Longitudinal Direction, Bracket

Welding) that are related to the movement of the welding robot.

c) Start/Stop welding

The Action Module transfers the welding voltage and current data to the Welding Machine Module, so that it is able to perform Welding Tasks.

d) Activate sensors

The Action Module transfers the sensing command to the Sensor Module in the *Task Executer*. The Action Module uses sensing data that is provided by the Sensor Module, in order to generate the next movement by the welding robot. 'Activate sensors' are necessary in performing Moving, Welding and Sensing Tasks.

2) Motion Generator Module

The Action Module transfers the motion command to the motion generator module, when the motion of the torch is necessary to perform tasks. The motion generator module generates the trajectory of the welding torch by using forward kinematics and inverse kinematics, and transfers the angle data of each motor to the servo module in the Task executer.

#### 4.2.4. Modules of the Task Executer

The modules of the *Task Executer* are the interface of hardware connected to the 'RRX3'. The *Task Executer* controls the AC servo motor by performing USB communication with the motion controller. The *Task Executer* performs real time communication (RS232, Digital I/O) with the laser sensor, proximity sensor, and shock sensor, and transfers welding data (voltage and current) to the welding machine controller through RS485 communication. The *Task Executer* consists of the Servo Module, Sensor Module, Welding Machine Module, and the ON/OFF Module.

1) Servo Module

The Servo Module transfers the angle data of each motor, calculated by the Motion Generator Module, to the motion controller, which controls the AC servo motor drivers. Communication between the Servo Module and the motion controller is performed through the USB.

2) Sensor Module

The Sensor Module transfers environmental data, which comes from the laser sensor, proximity sensor, and shock sensor, to the *Task Manager* or to *Actions for Task* through RS232 communication or Digital I/O.

3) Welding Machine Module

The Welding Machine Module transfers welding data (voltage and current), provided by the Action Module, to the welding machine controller, and it receives the results of arc sensing through RS485 communication.

4) ON/OFF Module

The ON/OFF Module performs non-periodic functions such as ‘servo on/off’ and ‘open/close protection cap’ of the laser sensor. Therefore, the ON/OFF Module merely waits for a signal from *Action for Task* without any performance. It performs the only function corresponding to the signal from *Actions for Task*, and after the required function is completed, it reverts to the initial waiting state. The ON/OFF Module is necessary for the Laser Sensing Task because it opens and closes the protection cap of the laser sensor.

5. IMPLEMENTATION AND EXPERIMENT RESULTS

To robustly control the mobile welding robot, modules in the control software need to operate precisely within a given period. Therefore, the QNX is selected as the operating system, because it is well known to have a reliable hard-real time performance. The control software is developed using C language. To verify the configuration of the hardware and to confirm the operation of the modularized control architecture, the transverse/longitudinal movement and welding test is performed. Figure 7 shows the test results.

5.1. Example of performing Transverse Moving Task by combining modules

Figure 7-①~④ shows the test results of the transverse movement to the right. The sequence of the modules in the control software is shown during transverse movement as follows (Fig. 8):

- 1) The Action Module transfers the ‘transverse movement’ command to the servo module.
- 2) The servo module transfers the ‘lift body’ command to the motion controller.
- 3) After the body is lifted, the Servo Module transfers the ‘move sub body right’ command to the motion controller.
- 4) The Sensor Module receives ‘longi detected’ information and transfers it to the Action Module.
- 5) The Action Module transfers the ‘stop’ command to the Servo Module. The Servo Module then stops the motors.
- 6) The Action Module operates the motors in sequence until the ‘RRX3’ completes the transverse movement. The Sensor Module detects the longi and transfers the result to the Action Module, and the Action Module then transfers the ‘stop’ command to the Servo Module.

5.2. Example of performing Longitudinal Moving Task by combining modules

- 1) The Action Module transfers the ‘longitudinal movement’ command to the Servo Module.
- 2) The Servo Module transfers the ‘move forward’ command to the motion controller.

3) While the ‘RRX3’ moves in the longitudinal direction, the Sensor Module receives ‘U-shaped part detected’ information from the laser sensor and transfers this information to the Action Module.

4) The Action Module then transfers the ‘stop’ command to the Servo Module, and then finishes the longitudinal movement.

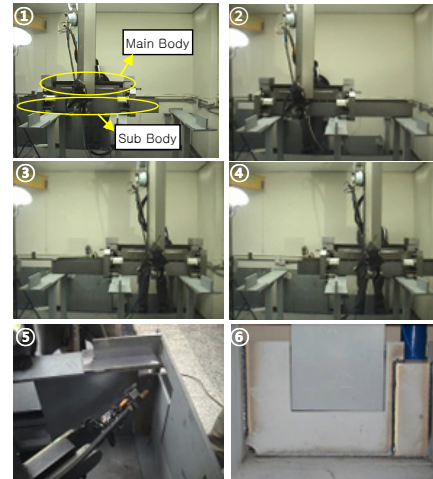


Fig. 7. Test (movement and welding) results of mobile welding robot ‘RRX3’

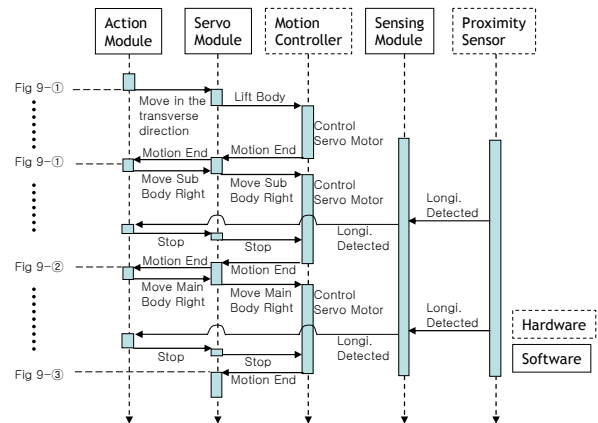


Fig. 8. Data transfer sequence between modules during movement in the transverse direction

5.3. Example of performing Weaving Welding Task by combining modules

Figure 7-⑥ shows the welding result of the U-shaped part. Weaving welding refers to the vertical welding performed by the zigzag motion of the welding torch. The sequence of the weaving welding is as follows (Fig. 9):

- 1) The Motion Generator Module transfers the ‘move welding torch from point A to point B’ command to the Servo Module.
- 2) The Servo Module transfers the ‘start motors’ command to the motion controller. The Welding Machine Module then transfers the ‘start gathering welding current’ command to

the welding machine controller while the welding torch moves from point A to point B.

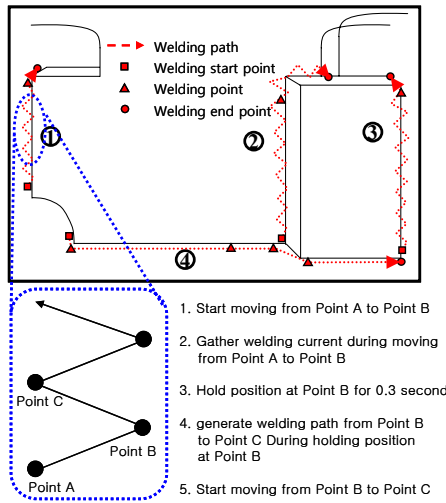


Fig. 9. Weaving welding sequence

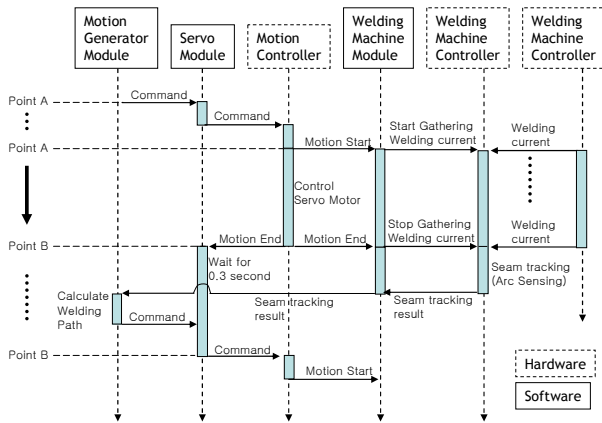


Fig. 10. Data transfer sequence between modules during weaving welding

3) The Servo Module waits for 0.3 seconds after the welding torch reaches point B. In the waiting time, the welding machine controller checks if the welding torch chased the required welding path successfully, using the collected current data.

4) The Motion Generator Module calculates the path of the welding torch from point B to point C with the result of the arc sensing.

5) The Motion Generator Module transfers the calculated position of point C to the Servo Module in the waiting time (0.3 second).

6) Go to the step 2 after the waiting time (0.3 second).

Figure 10 shows the communication sequences of the modules in the weaving welding task.

Consequently, the 'RRX3' detects the longi and moves in the transverse direction. In addition, the robot performs the welding task, while sensing the welding points and chasing the welding path. The configuration of the hardware and

operation of the modularized control software architecture is confirmed by the test results.

## 6. CONCLUSION AND FUTURE WORKS

This paper described a development of the embedded robot controller hardware and the control software for an autonomous mobile welding robot. The embedded controller and control software was applied to the autonomous mobile welding robot and it was able to execute the following tasks: autonomous movement, bracket welding and laser sensing. However, in order to develop an embedded type main controller, 12 AC servo motor drivers and a CPU board were installed in the small space. Because of this, safety from noise and heat was verified. In the future, the robustness of the embedded controller will be verified by a reliability test.

This paper described a development of the embedded robot.

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