

Rail Running Mobile Welding Robot 'RRX3' for Double Hull Ship Structure

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Abstract: 'Seoul National University' and 'Daewoo Shipbuilding & Marine Engineering' in Korea jointly developed a mobile welding robot, the 'Rail Runner' (RRX), which is able to freely move in both transverse and longitudinal directions, and perform welding tasks in double hull structures. Recently, RRX2, (the second version of RRX), was presented at 'Robotics and Applications 2007'. In this paper, the design, manufacturing, and application of RRX3, the third version of RRX, is described. The moving mechanism of RRX, which is able to move freely in a double hull structure, has two functions. 1) To move in a longitudinal direction by driving wheels using longi. faces as 'rails', and 2) To move in a transverse direction by sliding along supporting longi. faces using extension arms. The body of the RRX3 is composed of a 12-axis, 6-axis mobile platform that supports the RRX moving mechanism and a 6-axis welding robot to do the welding job. The main point in designing RRX3 is to make it capable of passing through a 600mm×800mm sized access hole, the entrance into an enclosed double hull structure. The full size of the manufactured RRX3 is 1825mm×495mm×569mm, and thus the RRX3 is able to pass through an access hole. The weight is 250kg with a 6-axis mobile platform, 6-axis welding robot, and mounted controller.

1. Introduction

Autonomous welding robots using multi-joint manipulators have been utilized in many shipyards since the 1990's. Unlike in a double hull structure, automation in a single hull structure has steadily developed in the shipyard industry. However, in enclosed double hull structures with longitudinal stiffeners (Longi.) which act as obstacles in the automation of welding tasks, welding tasks need to be performed by manual welders. Therefore, the development of an autonomous mobile welding robot that can be applied to closed double hull structures is necessary.

'Seoul National Univ.' and 'Daewoo Shipbuilding & Marine Engineering' in Korea have jointly developed an autonomous mobile welding robot, 'the Rail Runner' (RRX), which is able to freely move in transverse and longitudinal directions, and perform welding tasks in double hull structures. Recently, RRX2, the second version of RRX, was presented at 'Robotics and Applications 2007' (Kyu-Yeul Lee et al., 2007). In this paper, the design, manufacturing and application of RRX3, the 3rd version of RRX, is described.

1.1 Double Hull Structure

A double hull structure consists of top and bottom plates, girders and transverse web floors. The two plates cover the top and bottom of the double hull structure. The girder and transverse web floors divide the double hull structure into many closed sections. In each section, many reinforcing longitudinal stiffeners (Longi.) are arranged in parallel and they contain many small reinforcing stiffeners (Fig. 1).

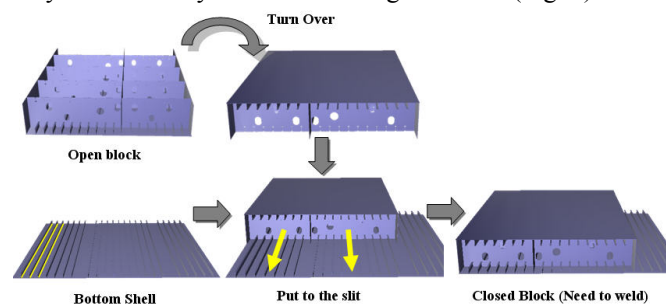


Fig. 1. Manufacturing of double hull structure

The inner features of a double hull structure are shown in Fig. 2. The moving directions of the inserted welding robot are defined as longitudinal direction and transverse direction.

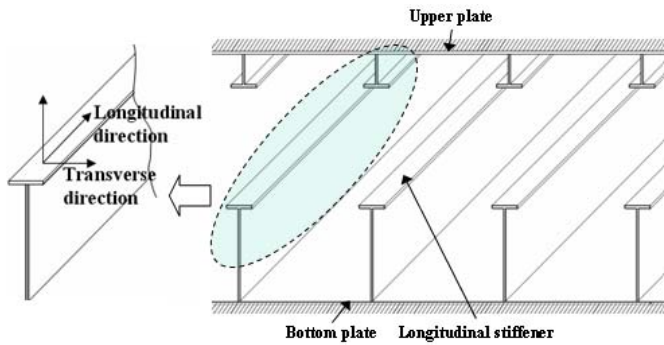


Fig. 2. Features of inner double hull structure

2. Related Works

'DANDY' is one type of 6R manipulator and has been typically used in single hull structures at the Daewoo Shipbuilding & Marine Engineering shipyard in Korea. A worker uses this 6-axis robot for welding and moves it to the next welding location with an overhead gantry crane installed on the ceiling of the manufacturing factory. 'DANDY', however, cannot be used in a double hull structure because the gantry crane is not able to handle the robot in this enclosed double hull structure. (J. H. Lee et al., 1998).

Leoncio Briones et al. in Chile developed a wall-climbing robot intended for inspection in nuclear power plants. This robot climbs both curved and flat walls to inspect cracks in the outer concrete wall of facilities in nuclear power plants. This robot is composed of three bodies connected serially. Pneumatic cylinders on the front and rear bodies are operated by turns to attach the robot to the wall. While one of the two attachable bodies is operating its pneumatic cylinder, the remaining unattached bodies iterate extending and contracting in proceeding direction to climb the wall. It weighs 30kg and its payload is 75kg in driving on a plane. However, it takes a lot of time for this robot to move because of the limitations of the crawling mechanism, and this robot is not able to overcome obstacles like Longi. in the double hull structure of a ship. Therefore it could not be applied to a double hull structure (Leoncio Briones et al., 1994).

IAI (Industrial Automation Institute) in Spain developed a wall-climbing robot, REST2, for butt welding tasks (welding two pieces of steel plates side by side) in a shipyard. This four-legged robot climbs steel wall using electronic magnets at the ends of the legs. The moving mechanism of REST2 is composed of two legs moving in the intended direction while the other two legs are attached to the wall using electronic magnets. This robot is economical in energy consumption so it can move without being connected to a power line. However, it takes too long for this robot to move because of the limitations with the 4-legged crawling mechanism also isn't able to overcome obstacles like Longi. in a double hull structure. Therefore the REST2 also isn't applicable (Manuel armada et al., 2002a).

ROWER 1 was also developed by IAI in Spain. This robot moves like a spider with four legs capable of extending and contracting. This robot is able to autonomously move,

overcome obstacles and is capable of performing welding tasks in a double hull structure. However, this robot needs to be disassembled into seven subsections to be inserted into a double hull structure because it is too heavy (350kg) and too large (1380mm × 700mm × 250mm). In addition, after being inserted into the double hull, the seven disassembled subsections need to be re-assembled. Therefore 'ROWER 1' cannot be applied in the shipyard (Manuel armada et al., 2002b).

In the Hitachi-Zosen shipyard (Japan), an NC painting robot was developed to paint inside a double hull structure. This robot consists of a self-driving carriage, an expandable placer and a 6-axis manipulator. The 6-axis manipulator is used for painting. The role of the placer is to move the manipulator to the selected location in a division surrounded by floors and girders. The self-driving carriage, which mounts the placer and manipulator, runs on the faces of two longitudinal stiffeners without rails by utilizing two sets of magnetic crawlers. There is, however, a limitation to the robot. The location of the 6-axis manipulator is limited by the reach of the placer in the transverse direction (Tatsuo Miyazaki, et al., 1999).

'A transferring device for overcoming obstacles by elevating and sliding, developed by Samsung Heavy Industry Co. Ltd., is able to freely move in transverse and longitudinal directions and is capable of performing welding tasks in double hull structures. This robot moves in a longitudinal direction using driving wheels. It moves in a transverse direction with legs capable of extending and contracting, and sliding device on the base side of the main platform. The legs extend to elevate the main platform to the level of the Longi. face and then the main platform slides to the next work space via the sliding device while the extended legs are being folded by the Longi. This robot has already been applied in the shipyard of Samsung Heavy Industry; however, it takes too long to move in a transverse direction and needs high-capacity motors because the main platform of this robot must be elevated to the level of obstacle when the robot goes over it.

Therefore, this research is intended for the development of the RRX3, considering the above shortcomings of related works with respect to time-consumption in movement, weight, and insertion into a double hull structure through its access hole.

3. Moving mechanism

3.1 Moving mechanism of 'Rail Runner' (RRX)

The moving mechanism of the RRX enables RRX to perform movement in both longitudinal and transverse directions in a double hull structure. There are two kinds of moving mechanisms with respect to the movement direction of the RRX: longitudinal direction and transverse direction.

3.1.1 Moving mechanism in longitudinal direction

The RRX moves in a longitudinal direction with driving wheels on a driving wheel section using Longi. faces as rails (Fig.3).

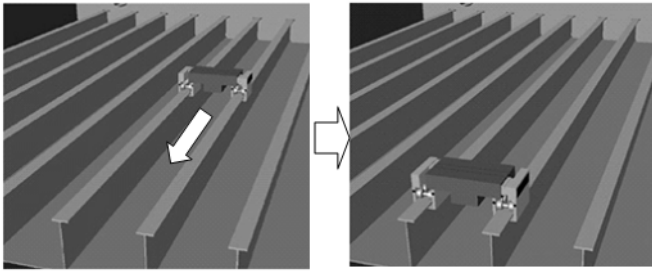


Fig. 3. Moving mechanism in longitudinal direction of RRX

3.1.2 Moving mechanism in transverse direction

The RRX platform is placed on the faces of the two longitudinal stiffeners with the driving wheels at the initial state of moving mechanism in transverse direction. The RRX then extends its arm to the next Longi. After the extended arm is supported on two longi., the main platform of the RRX slides to the next work space. As the sliding of the main platform completes, the remaining extended arm begins to contract. The moving process of the RRX is completed with arm contraction (Fig.4).

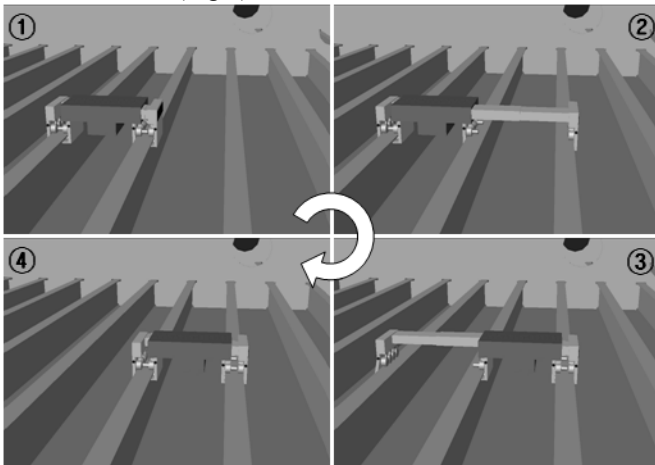


Fig.4. Moving mechanism in transverse direction of RRX

3.2 Moving mechanism of RRX3

The moving mechanism of the RRX3 was developed by applying of the RRX moving mechanism. The RRX3 mobile platform is composed of an upper sliding section, lower sliding section and driving wheel section. The moving mechanism in a longitudinal direction is embodied by driving on the Longi. face with the wheels of the driving wheel section. The moving mechanism in a transverse direction is also a result of applying the basic concept of the moving mechanism of the RRX, which is embodied by sliding sections of a mobile platform. Fig. 5 is a conceptual figure showing the alternation of the extension arms of the RRX with the lower sliding section in the RRX3 to embody the moving mechanism in transverse direction.

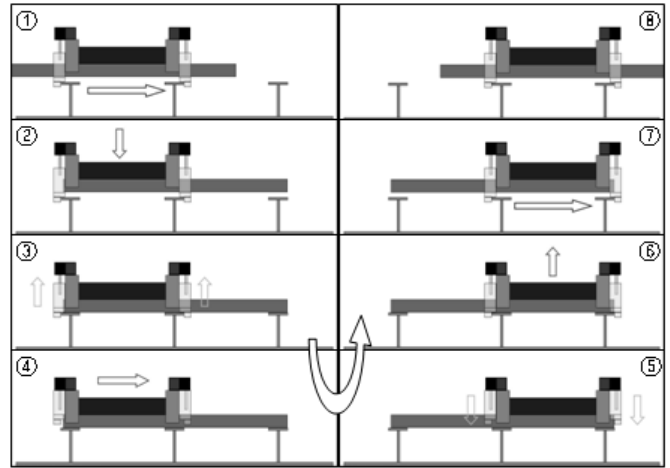


Fig. 5. Moving mechanism in transverse direction of RRX3

In Step 1 of the moving mechanism in a transverse direction, the lower sliding section moves in the transverse direction until it can cover three longitudinal stiffeners (Fig. 5-1). In Step 2, the driving wheel section lowers the lower sliding section, and the upper sliding section is placed on the lower sliding section (Fig. 5-2). In Step 3, as the lower sliding section is supported on the longitudinal stiffeners, the driving wheel section begins elevation. In Step 4, the upper sliding section moves transversely, guided by rails on the lower sliding section. In Step 5, after the transverse movement of the upper sliding section finished, the upper sliding section begins to descend. In Step 6, as the driving wheels become supported on the Longi., the lower and upper sliding sections begin elevation. In Step 7 and 8, the lower sliding section moves transversely until the RRX3 platform moves into its initial posture.

4. Design of RRX3 Mobile Platform

The mechanical composition of the RRX3 mobile platform is composed of three main assemblies: upper sliding section (top), lower sliding section (below), and driving wheel section (center) (Fig.6).

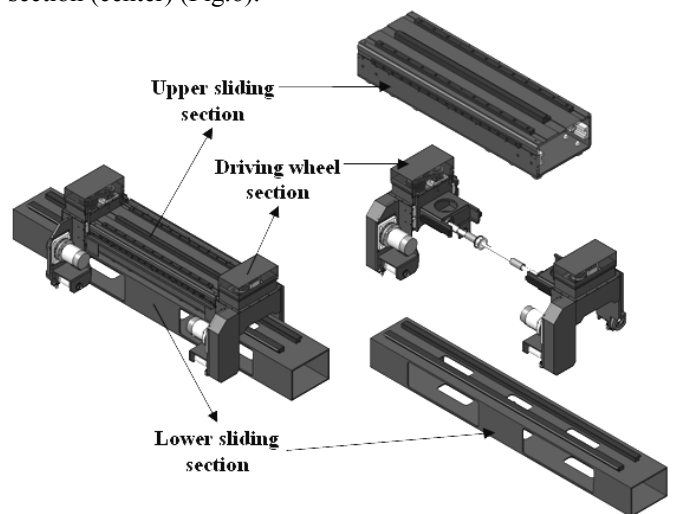


Fig. 6. Overall mechanical arrangement of RRX3 mobile platform

The upper sliding section has two functions. It is able to slide on the lower sliding section, and control the width between driving wheels because the width of longitudinal stiffeners varies according to the kind of ship. The lower sliding section functions as a guide rail when the 'Rail Runner' platform moves in a transverse movement, additionally, encloses the main control box. The driving wheel section also has two functions. It is able to drive the whole platform in a longitudinal direction and lift or lower the upper and lower sliding sections for transverse movement.

5. Development of Self-Driving Mobile Welding Robot

5.1 Design of 6-Axis Welding Robot

The overall '3P3R (PPRPRR)' welding robot is shown in Fig. 7. This robot is composed of a 3-prismatic-axis and a 3-revolute-axis. The motors for all joints drive each joint via a harmonic drive system for reducing backlash.

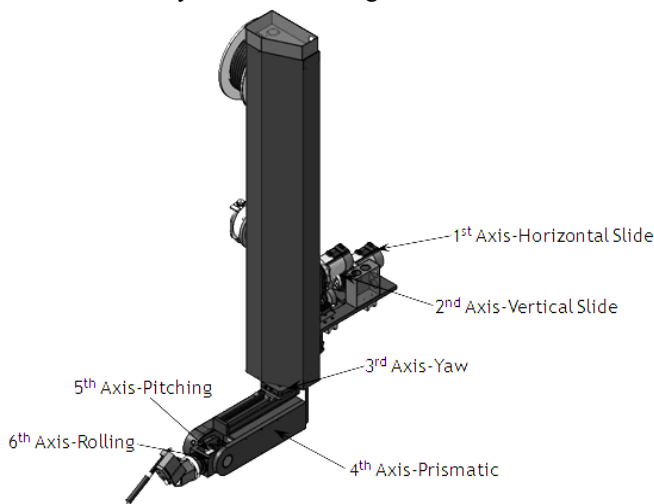


Fig. 7. Overall 6-axis welding robot

The end-effector of this robot is designed to be able to endure a payload up to 5kg for welding. There are several pieces of equipment such as welding wire spools, wire feeder, torch cable, etc. which are necessary for welding tasks. This robot is designed to be able to carry all these so that workers only replace the welding wire spool attached the top of the 6-axis welding robot when it is used up.

5.2 Combination of RRX3 Mobile Platform and 6-Axis Welding Robot

The 6-axis welding robot is designed for performing welding tasks and the RRX3 mobile platform is designed to be able to move freely in the double hull structure of a ship. Thus the RRX3 mobile welding robot is composed of the 6-axis welding robot and the 6-axis mobile platform. The configuration of the RRX3 is represented in Fig. 8.

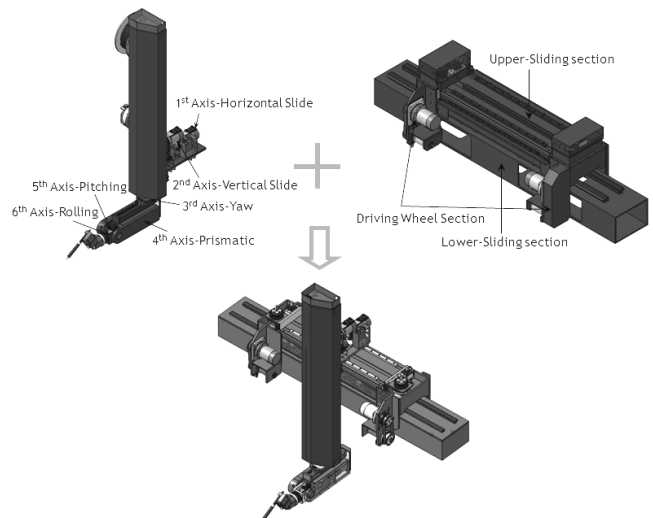


Fig. 8. Combination of RRX3 mobile platform and 6-axis welding robot

The 1st axis of the 6-axis welding robot is coupled by linear motion guides (LM guide) at the top plate of the RRX3 mobile platform. Two rails of the LM guide are attached to the top plate of the RRX3 mobile platform, and four blocks of the LM guide are attached under the plate of the 1st axis (Fig. 8). Therefore the 6-axis welding robot is able to move relative with the mobile platform. Fig. 9 shows a photograph of the manufactured mobile welding robot, RRX3.

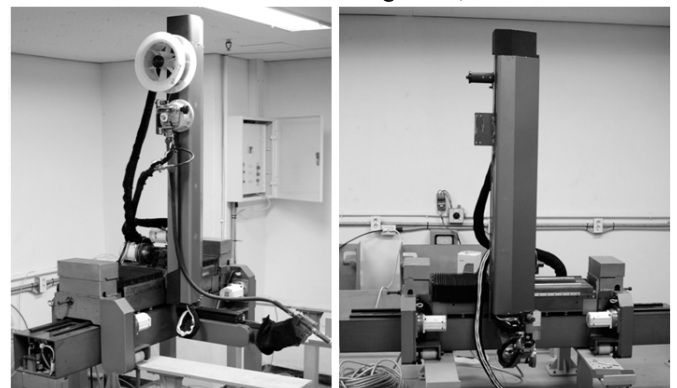


Fig. 9. Manufactured RRX3 mobile platform and 6-axis welding robot.

The specifications of the manufactured RRX3 are shown in Table 1.

Number of Axes	Mobile Platform	6
	Welding Robot	6
	Total	12
Weight [kg]	Mobile Platform	119.5
	Welding Robot	67.5
	Controller	53.0
	Total	250.0
Size [mm] (L × W × H)	Posture for welding task	1825×495×1537
	Posture for passing through access hole	1825×495×569

Table 1. Specifications of RRX3

5.3 Passage through the access hole

The main problem in designing the RRX3 was how it could be passed through the 600×800mm²-sized access hole. The access hole is the entrance into the enclosed double hull structure.

The 6-axis welding robot of the RRX3 is designed to rotate with respect to the RRX3 mobile platform. The size of the manufactured RRX3 is 1825×495×569mm³ for posture for welding task. But after rotating the 6-axis welding robot, the size of the RRX3 becomes 495×569 mm² is small enough to be inserted in the double hull through the access hole.

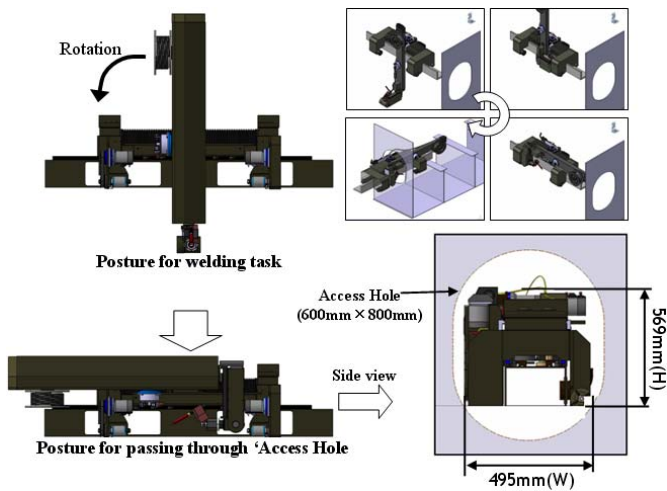


Fig. 10. Passage through the access hole

6. Validation of the moving mechanism

In Fig. 12 the manufactured mobile welding robot, the RRX3, shows the moving mechanism in a transverse direction. In the validation test of the RRX3, it successfully completed the transverse-direction movement in 1.5 minutes, and was also capable of moving in a longitudinal direction without any problem.

In addition, the welding performance of the RRX3 was validated by performing welding tasks of good quality in the field at the DSME shipyard (Fig. 11).



Fig. 11. Validation of welding task of RRX3



Fig. 12. Validation of RRX3 moving mechanism in transverse direction

7. Conclusion

In this paper, the development of the mobile welding robot, the RRX3 (the 3rd version of the RRX) -- which can drive itself and perform welding tasks in a double hull structure -- is described. The RRX3 is able to move in both transverse and longitudinal directions while performing welding tasks in double hull structure. Future work such as lessening the weight of the RRX3 and the development of a device which inserts and retrieves the RRX3 remain.

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