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# DELIVERY OF AN ADVANCED DOUBLE-HULL SHIP WELDING SYSTEM USING ROBOCRANE®

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## ABSTRACT

The Office of Naval Research has sponsored a collaborative effort between the Naval Surface Warfare Center Carderock Division, Advanced Technology and Research Corporation, Newport News Shipbuilders, the National Institute of Standards and Technology (NIST). Phase I of this effort is nearing completion to autonomously weld double-hull ship sections together. In order to accomplish the delivery of industrial equipment (welder, weld robot, power supply) to the work-site, an advanced crane concept called "RoboCrane" was employed. Typically, a crane equipped with conventional controls would be used to deliver worker-assisted and controlled welding systems. But, the expense, inefficiencies, and the unsafe environment that the project imposes on workers make it a more suitable robotic application. RoboCrane is used to pick-up, deliver, and retrieve advanced welding systems using remote control to/from the work-site where double-hull ship sections are to be joined by welding. The paper provides description of the RoboCrane application to advanced double-hull ship construction, including system configuration of RoboCrane and the weld system, control and sensory feedback, and other applications considered.

## INTRODUCTION

### *Double Hull Ships*

Double-hull tankers have been in special product service operation for many years. Typically, these ships have carried hazardous cargo, low temperature liquid natural gas (LNG) and liquid petroleum gas (LPG), chemical and other special products. (Michaelson and Roseman) Since the Oil Pollution Act of 1990 (OPA90), a mandate was set that all product carriers operating in United States waters be double-hulled by the year 2010. (Rodd, et. al.) The Advanced Double Hull design concept includes a longitudinally-framed ship structure with long, uninterrupted, unidirectional assemblies. (Ford, et. al.)

Double hull ship cells, made from 19 mm (0.75 in) thick steel and measuring a minimum of approximately 1.2 m wide x 1.2 m high x up to 15 m long (4 ft x 4 ft x up to 50 ft), stack creating an up to 18.9 m (62 ft) high and up to 41.5 m (136 ft) wide ship profile.* Openings to the ship cells (ship cell entrances) measure approximately 0.46 m wide x 0.76 m high (18 in x 30 in). These cells are therefore, small spaces for humans to work. Similarly, advanced, double-hull, combatant ship cells can have even smaller dimensions measuring 0.9 m x 0.9 m x up to 15 m long (3 ft x 3 ft x up to 50 ft long) further hindering humans from working inside the cells. (Gallagher, et. al.)

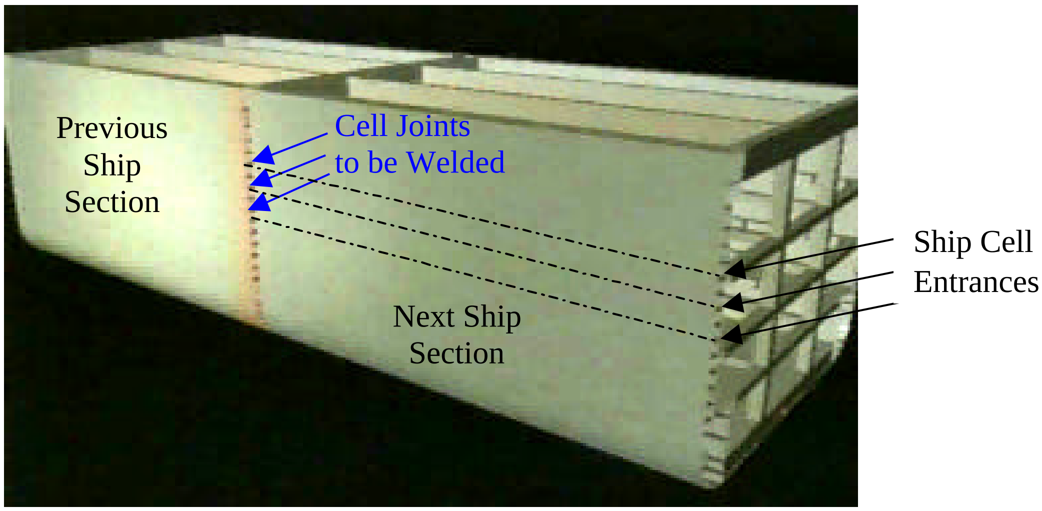
### *Advanced Double Hull Ship Welding*

Through a collaborative effort sponsored by the Office of Naval Research, the Naval Surface Warfare Center Carderock Division, Advanced Technology and Research (ATR) Corporation, Newport News Shipbuilders (NNS), and the National Institute of Standards and Technology

* The measurements listed are maximum breadth and depth, respectively, from 122,850 DWT Tonsina Class Double Hull Tanker and from 40,000 DWT Double Hull Tanker Commercial Design PD-328. (Michaelson and Roseman)

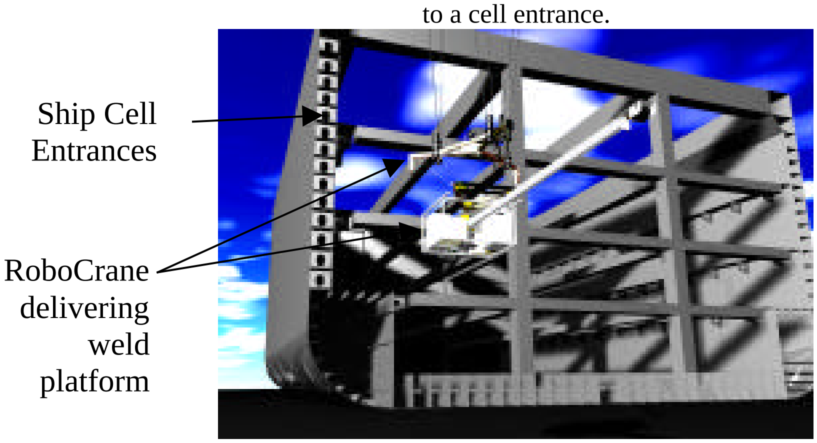
(NIST), are conducting a study of advanced construction of double-hulls. To date, Phase 1 efforts to weld double hull ship sections autonomously (see FIGURE 1) have been completed. This work has included modeling the ship cell and the cell joints between previous and next ship sections; developing an autonomous weld seam locator system; developing an autonomous weld platform including an integrated weld robot, weld system, and weld robot delivery system; and, developing a remote, weld platform, delivery system.

FIGURE 1: Graphic of the advanced double hull ship construction concept showing two ship sections being joined and the entrances to ship cells providing access to the internal cell joints to be welded.



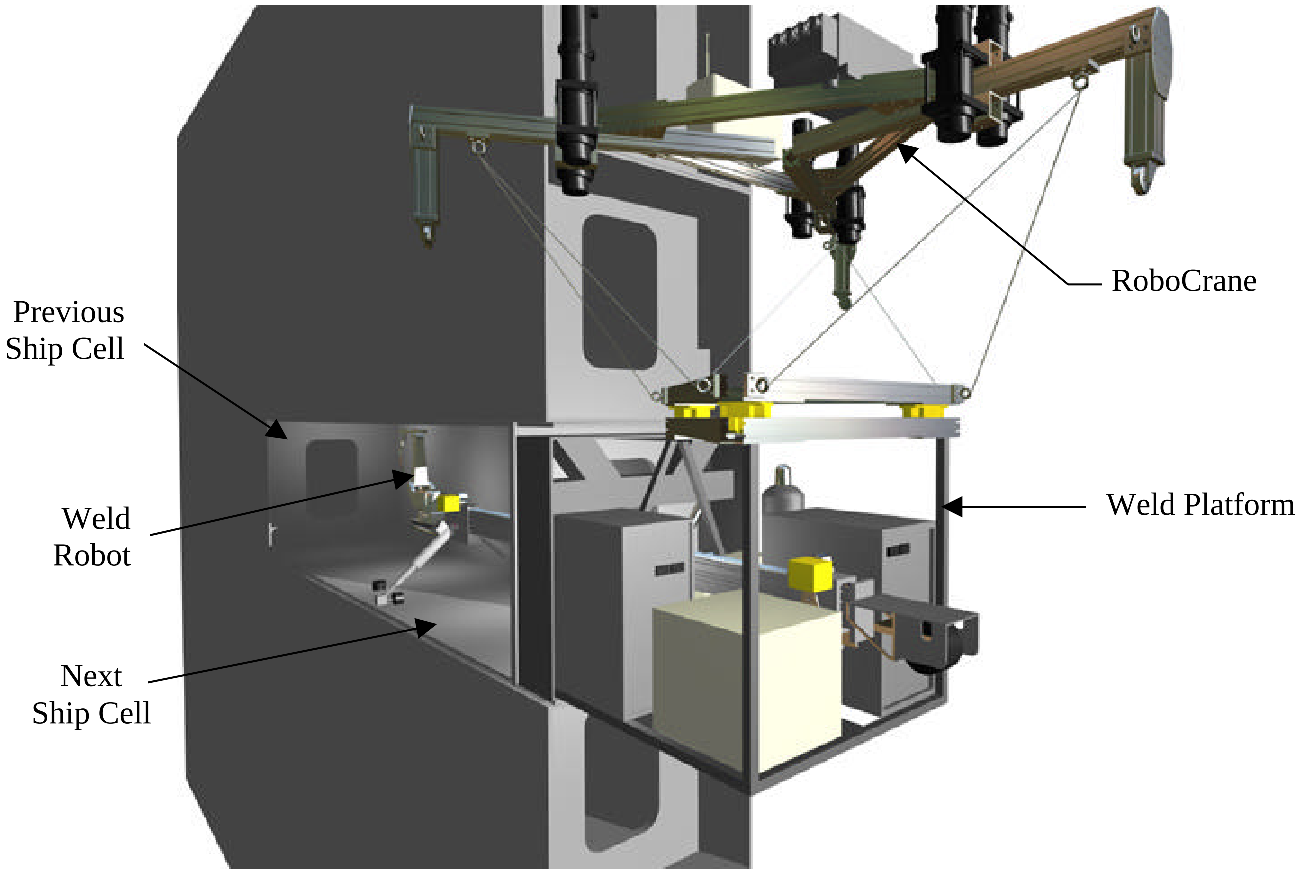

The mock-up used for the Phase 1 study was the non-combatant ship-cell size fabricated from 19 mm (0.75 in) thick steel. It measured 1.2 m wide x 1.2 m high x 2.4 m long (4 ft x 4 ft x 8 ft long) with a cell entrance measuring 0.46 m wide x 0.76 m high (18 in x 30 in). Three main components were needed to accomplish the remote and autonomous double hull ship welding on the mock-up: a weld robot with welder to weld the cell butt joint, a weld platform that positioned the weld robot near the target seam found the weld seam, and welded the seam, and a robot crane that remotely deployed the weld platform. FIGURES 2 a and b graphically depicts the advanced double hull ship welding scenario.

FIGURE 2a: Graphic showing the profile of a ship section as RoboCrane delivers a weld platform to dock to a cell entrance.



The 975 kg (2150 Lb.) weld platform, measuring 1.6 m x 1.6 m x 1.3 m high (66 in x 66 in x 53 in high), was attached to the cell mock-up during demonstration. The weld platform included static and dynamic cell attachment mechanisms, a weld torch and power supply, a robot arm and controller used to position the weld torch, a 3.7 m (12 ft) long extendable boom used to position the robot near the weld, and a frame support housing. An advanced robot crane, called RoboCrane®, was used to dock the weld platform to the cell entrance. The focus of this paper is the weld platform deployment system (RoboCrane) as used for advanced double hull ship construction and other applications.

FIGURE 2b: Graphic showing the weld platform docked to a ship cell using RoboCrane. A telescoping boom carrying a weld robot is being deployed from the weld platform and into the cell for welding the butt joint between the previous ship cell and the next cell.




## CRANES APPLIED TO DOUBLE HULL CONSTRUCTION

### *Potential Conventional Practice*

In order to access the ship cell entrances remotely in the Advanced Double Hull Ship Construction (ADHSC) concept, conventional cranes and their controls do not appear to be feasible. Typically, cranes provide load hoist with only vertical motion control. Consequently, loads are free to sway and rotate, especially where wind is a factor. This can produce inefficiencies, for example, while attempting to maneuver heavy, steel, sheet stock, bulky objects, and/or large assemblies associated with typical ship construction tasks.

Docking a weld platform to a ship cell for the advanced double-hull weld process, requires 6.4

mm (1/4 in) tolerance at the docking point that can be at a height of 15 m (50 ft) or more. Without precise placement of the weld platform, heavy loads can easily bind causing damage to the ship cell and/or the weld platform. To avoid this problem, suspended crane loads are typically guided by personnel, who push or pull the load or by taglines controlled by up to several tagline operators. Precision control of the suspended load is, therefore, difficult to achieve without very skilled crane operators and correctly-positioned tagline operators. When using tagline operators on suspended loads at a load height of 15 m (50 ft), tagline operators must be far from the docking point. To put personnel near the docking point requires scaffolding or other fixtures to allow personnel direct access to the site. Besides the safety and prior scaffold set-up aspects, at least 4 personnel (a crane operator, 2 tagline operators, and at least one load positioner at the target location) would be needed for this operation.

Communication is also a challenge during load movement via cranes. In many situations, the crane operators view is obstructed during load maneuvering. Site personnel use hand-signals or talk to the crane operator to communicate load movement requests. This causes, at a minimum, slow material handling/positioning from communication delays and can prevent the crane operator from accurately positioning the load. The work area is typically noisy, which also hinders verbal communication with the crane operator, as well. These load-movement and communication challenge scenarios are typical throughout the shipbuilding and other crane-assisted processes. This causes hazardous, tedious, and/or labor intensive operations equating to inefficient manufacturing practices.

To access and dock the weld platform (or other suspended loads) properly in the ADHSC concept, the single crane operator needs complete six degree-of-freedom (DOF) control of the suspended load. So the potential expense, inefficiencies, and the unsafe environment that the project imposes on workers and process equipment make it suitable for robotic application.

## Advanced Crane Method

The National Institute of Standards and Technology (NIST) has been studying the control of crane-suspended loads for many years. Within the NIST Manufacturing Engineering Laboratory, the Intelligent Systems Division has been developing an intuitively controlled and reconfigurable, robot crane system, called "RoboCrane®."

The NIST RoboCrane is an advanced robot crane system with controlled dexterity in all six degrees-of-freedom (x, y, z, roll, pitch, and yaw). Modeled after the Stewart platform, parallel-link manipulator (Albus, et. al.) (see FIGURE 3a showing a typical RoboCrane configuration and FIGURE 3b showing a photograph of the RoboCrane attached to a bridge-trolley crane), the RoboCrane uses cables as the parallel links and winches as actuators. This configuration creates a very large work volume with platform constraint in all six degrees-of-freedom.

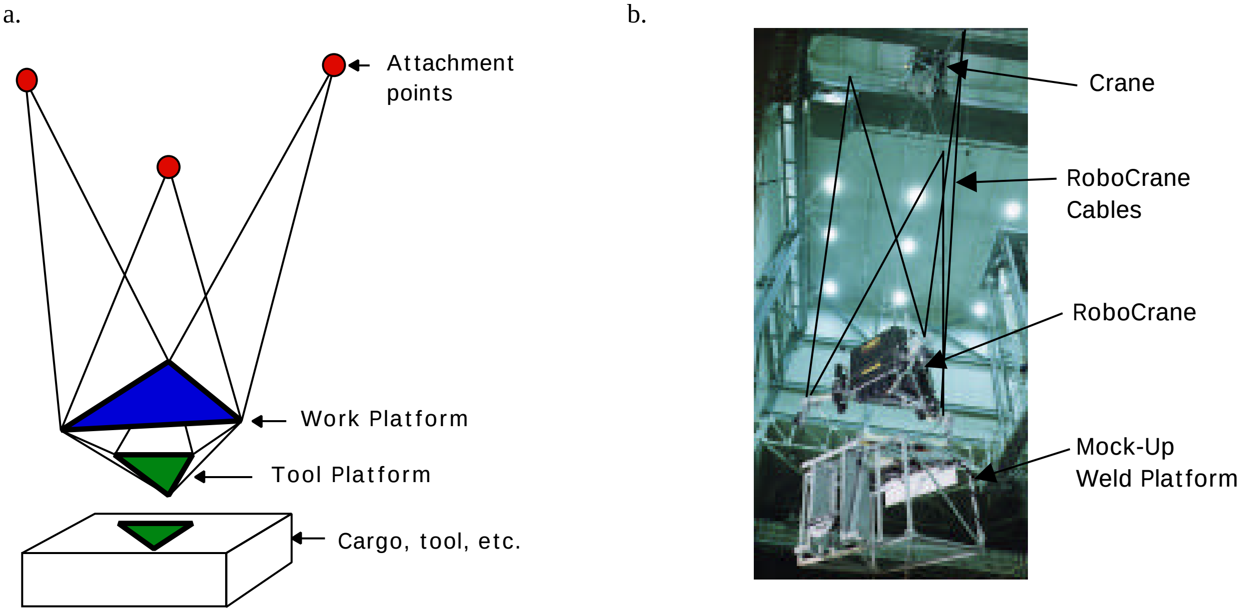
Cable winches can be mounted on or off the work platform and suspension of the platform can be from fixed supports (wall and/or ceiling) or movable supports (gantry crane, boom crane, movable truss structure). A tool platform suspended below the work platform, provides compliant tool fixturing to RoboCrane because the tool platform support cables can go slack while tools or equipment are being attached. When lifted by RoboCrane, the tool platform cables become taught and the tool is fully constrained to RoboCrane motions. The cargo, tool, or other equipment to be attached and maneuvered by RoboCrane have a standard mechanical interface to which the tool platform can attach rapidly. A sling or other attachment mechanism is also possible.

The accuracy of a 6 m (20 ft) version of RoboCrane at NIST is approximately 1 mm (0.04 in) along lateral axes and 9 mrad (0.5 deg) rotated from all axes. (Albus, et.al.) The RoboCrane work volume with full 6 DOF control is dependent upon the cable attachment point locations and platform size. For example, a RoboCrane configured with attachment points spaced 6 m (20 ft), has a platform center of gravity work volume of approximately 77 $m^3$ (1,762 $ft^3$).

Similarly, another RoboCrane prototype at NIST being used for the ADHSC concept has a work volume of approximately 2,633 $m^3$ (60,000 $ft^3$) with average lateral repeatability of approximately ±10 mm (± 0.4in). This form of RoboCrane is configured with onboard winches, a controller and remote sensing capabilities for full remote operator control. It is used to remotely pick-up and deliver a welding platform to the mock-up ADHSC site. Both RoboCrane configurations allow controlled rotations of approximately 0.5 rad (± 30 deg) in roll, pitch, and yaw.

FIGURE 3 a. Graphic of the RoboCrane configuration; b. Photograph of a RoboCrane, with onboard winches and controller and suspended from a bridge-trolley crane, maneuvering a mock-up weld platform toward the advanced double hull ship construction demonstration.

a. b.

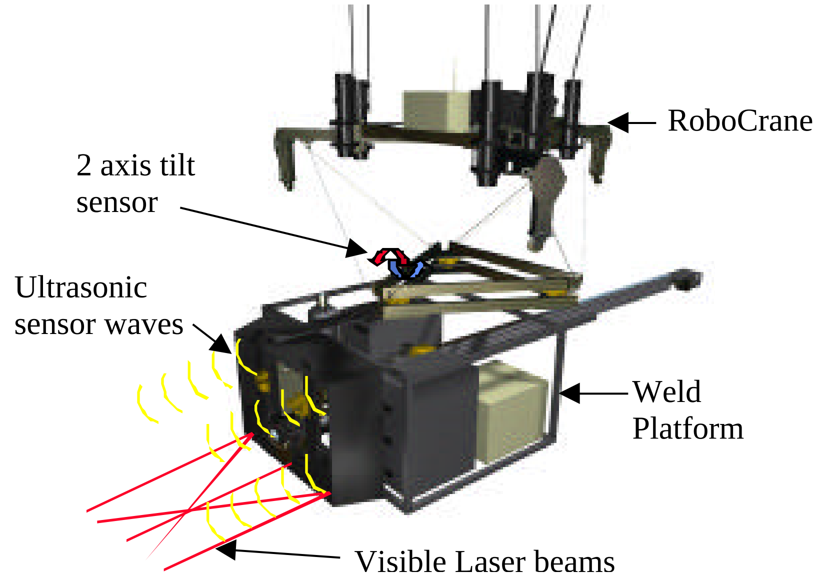



## *Advanced Crane Control*

Various control modes of the suspended work platform have been demonstrated, including: remote joystick, tele-operation, cartesian, joint, teach, force, offline-graphical, and constrained axis control. (Bostelman, et. al.) These modes can be used to control tools and equipment precisely while attached to the RoboCrane over complex surfaces. Various sensory interactive RoboCrane control methods have also been studied. Load cells attached to each RoboCrane cable have been used to provide information to cable- tension control algorithms so that cables are not overloaded, to provide for motion compensation of the platform, and to define the RoboCrane work volume by not allowing slack cables. Ultrasonic and tilt sensors have been integrated into a rapid platform-alignment algorithm and provided semi-autonomous assistance to the remote RoboCrane operator during weld platform delivery. Visible laser beams are used to aid the remote operator during the weld platform attachment to RoboCrane (via the tool platform) and during the weld platform attachment (dock) to the ship cell. FIGURE 4 shows a graphic of the weld platform remote delivery concept using lasers, a two-axis tilt sensor, and ultrasonic sensors. These sensors provide visual cues (from lasers) and semi-autonomous alignment (from tilt and ultrasonic sensors) to the ship cell during docking.

RoboCrane has also demonstrated semi-autonomous, open-loop welding along the seam between two clamped beams. With only the weld torch attached to the RoboCrane tool platform, two locations along the 1 m (3 ft) long seam were taught to the RoboCrane. The RoboCrane then drw a straight line between these two points to weld the seam together. Complex control of the RoboCrane using off-line graphical programming has also been accomplished.

FIGURE 4: Graphic showing the weld platform-mounted lasers and tilt/ultrasonic sensors used to provide feedback to the remote operator and alignment algorithm, respectively, during platform docking.




## *Other RoboCrane Applications Considered*

The RoboCrane is sufficiently stable for doing a variety of tasks that could aid workers toward advanced tool and equipment manipulation. The NIST RoboCrane testbeds have demonstrated:

- welding using teach and off-line programming control as the tool platform supports the weld torch and wire feed mechanism.
- grinding using force, teach, and/or off-line programming control as the work platform and compensates for grinder forces.
- material/equipment handling using joystick, teleoperation, or off-line programming control with a gripper, quick-change, or other grappling device attached to the tool platform. A remote operator maneuvers the load (e.g., equipment, beam, robot).
- pipe-fitting using constrained-axis joystick control with a pipe gripper attached to the tool platform. A remote operator maneuvers and holds a heavy pipe against another pipe to mate flanges for bolt insertion through the flanges.
- inspection of an object using a line-scanning laser attached to the tool platform while the scanner is maneuvered using teach or joystick control.
- bridge construction using two joysticks – one for each end of the 6 m (20 ft) long bridge section.
- waste storage tank remediation feasibility using joystick control of a mock-up 6 m (20 ft) long manipulator attached to the tool platform and passing the manipulator through a 0.5 m (18”) diameter opening.

We plan to study aircraft maintenance, flexible fixturing, and other useful large scale manufacturing applications in the near future. The flexibility of the RoboCrane concept allows any of the above applications to be addressed by simply attaching a different tool platform.

## SUMMARY AND

## CONCLUSION

Double-hull ships will be required for carrying petroleum products through U.S. waters by 2010. Conventional construction methods used to manufacture advanced double hull ships will result in difficult and inefficient methods in confined and difficult-access spaces. The Office of Naval Research sponsored a collaborative effort between the Naval Surface Warfare Center Carderock Division, Advanced Technology and Research Corporation, Newport News

Shipbuilders, and the National Institute of Standards and Technology (NIST), has developed an advanced double-hull shipbuilding concept. The concept uses three main parts: a weld robot with welder, a weld platform, and a robot crane, called RoboCrane. The RoboCrane is used to deliver the weld platform and weld robot under remote control, to the ship cell for internal ship cell welding purposes. Visual cues from lasers to the remote RoboCrane operator and an alignment sensing/algorithm method proved that the weld platform can be remotely delivered to the target ship cell entrance. The efficiency in this remote docking method eliminates the hazards of conventional tagline personnel and operator assisted alignment methods around the heavy load. Other RoboCrane applications have also been considered and their control and manipulation studies have proved feasible in many additional large-scale manufacturing areas.

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