RoboCrane Project: An Advanced Concept for Large Scale Manufacturing

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ABSTRACT

The RoboCrane is a cable driven, multi-purpose manipulator based on the Stewart Platform Parallel Link Manipulator. It provides six degree-of-freedom load control via teleoperative, graphic off-line programming, and hybrid control modes. Originally, the RoboCrane was developed under a Defense Advanced Research Project Agency (DARPA) contract to stabilize loads on conventional cranes. Currently, configurations have advanced to include land, sea, air-lifted, and space applications. It can be designed for high lift-to-weight ratio, stable gantry configurations, flexibility, precise maneuverability, and mobility over a variety of surfaces including very rough terrain. As part of the NIST mission, the Intelligent Systems Division provides research in, develops methods for, and applies intelligent systems technology to improve U.S. industry competitiveness [1] relating to manufacturing, including large scale manufacturing, such as: building, airstrip, bridge, and ship construction. The RoboCrane provides an intelligent machine enhancement or alternative to current construction methods.

1.0 Introduction

Although manufacturing is normally thought to include small scale assembly-line applications with repetitive tasks such as: pick-and-place operations, assembly, gripping, soldering, etc.; large scale manufacturing is just as important. Manufacturing of aircraft, ships, farm equipment, construction machines, and railroad rolling stock; construction of roads bridges, tunnels, and high rise buildings are just as vital to U.S. industry and infrastructure. Generally, technology advancement in construction is limited because the construction industry is not structured to provide incentives for investment in research and development.

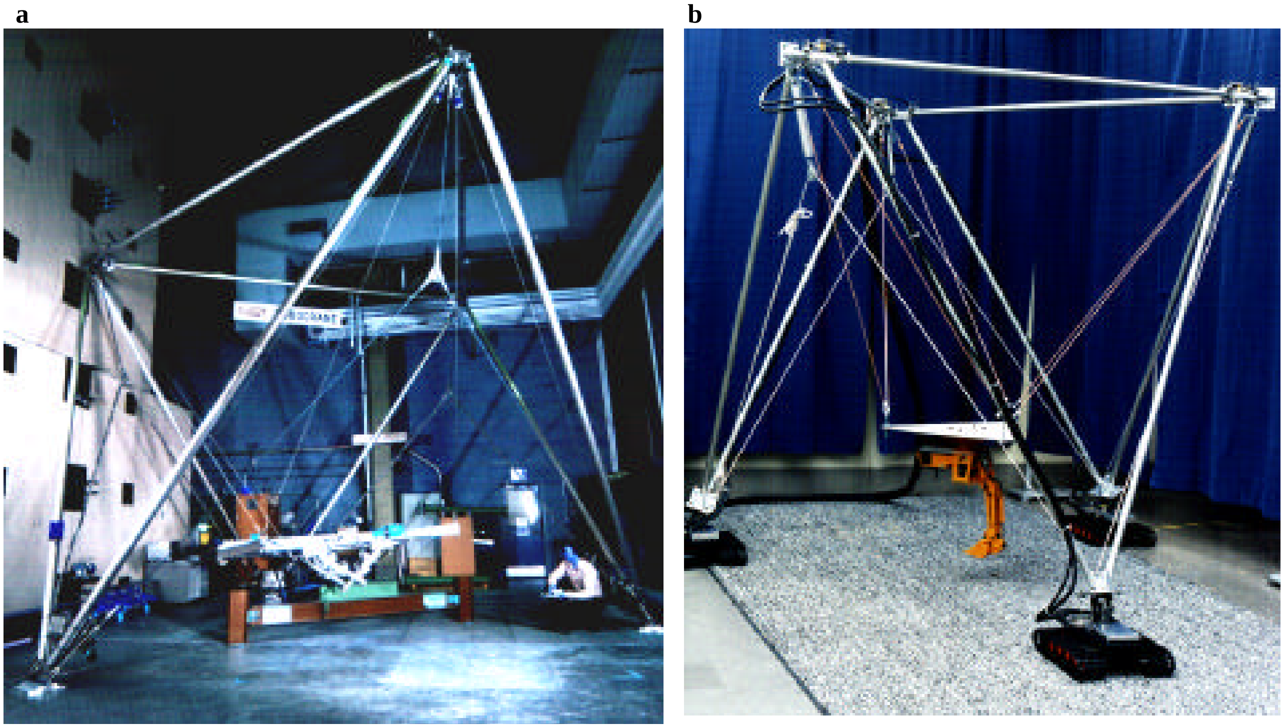
As a result, construction equipment is typically heavy, relatively expensive, and relatively low technology. For example, typical cranes are incapable of precisely positioning large objects or manipulating power tools because the load is constrained only along the vertical axis. The RoboCrane [2,3] provides precise six degree of freedom control of loads and intelligent control technology that opens up new vistas for heavy manufacturing and construction. The RoboCrane enables both manual and computer numerical control of tools and parts for a variety of tasks such as welding, grinding, gripping, sawing, assembly, etc. This makes it possible for construction operations to be scheduled and controlled similar to a small scale manufacturing assembly-line with known material placement, preprogrammed position and trajectory information.

Multiple RoboCrane prototypes have been developed at NIST to study a variety of potential applications [4] in large scale manufacturing. The most recent developments are in bridge and airstrip construction for both civilian and military use. A 6 meter octahedral system has been used to demonstrate heavy load manipulation, sawing, grinding, gripping, welding, and assembly tasks under teleoperative, preprogrammed, and hybrid control modes (see figure 1a). Accuracy of this prototype has been measured at up to 1 mm in translation and angular motion of approximately 0.5° throughout a minimum 100 cubic meter work volume. Mobility has been demonstrated with a 2-meter radio controlled model (see figure 1b). Bridge construction has been demonstrated with a 1/6th scale model Robocrane. Modular bridge components have been rapidly and precisely assembled with six degree-of-freedom control (see figure 7b).

The following sections discuss: current crane methods in large scale manufacturing, NIST intelligent machine research and development efforts using the RoboCrane Integration Testbed, potential use of the RoboCrane in large scale manufacturing, and other potential RoboCrane unmanned ground applications. Summary, conclusions, and references sections follow.

FIGURE 1. a) 6-Meter and b) 2-Meter NIST RoboCrane Prototypes. Precision tool manipulation while attached to a flexible mobile gantry structure.

a **b**



2.0 Conventional Large Scale Manufacturing

2.1 Conventional Cranes

A wide variety of cranes are currently available for lifting loads ranging from 20 kg to 1000 kg. However, the load is typically suspended from a single point and is free to sway, and rotate in a variety of ways. Load control is determined by the skill of the crane operator, sometimes assisted by workers using tag lines or manually manipulating the load to prevent sway and to make fine alignments of the load. Good communication between the workers and the crane operator are required, and much depends on the skill and efficiency of the workers to grab, place, and fasten the load in place.

2.2 Crane Load Control

Crane load control has improved little since cranes were invented. Tag lines controlled by riggers are the typical method used to both dampen load swing and position the load along axes other than vertical. Combining counteracting forces by the tag line operator, his/her "feel" of where the load will swing, and visual feedback, the crane operator can successfully, and even precisely, maneuver light loads. But, this places the riggers at or near the load and in a potentially hazardous area.

Other methods of load control have included tag lines attached to the crane boom or housing, and actuating these lines upon sensing their tension, such as the Rider Block Tag Line Control System [5]. This system moves close to the sheave block above the hook, allowing the load to move freely at the hook. This system therefore, provides some stability of the hook and in turn, localized stability of the load, but provides no z-axis rotational control of the load.

Load sway may also be stabilized by using the crane control system to provide accelerations of the support point timed to oppose pendulum load swing. However, this does not stop yaw and pitch rotations of the load.

3.0 Intelligent Machine R&D: RoboCrane Integration Testbed

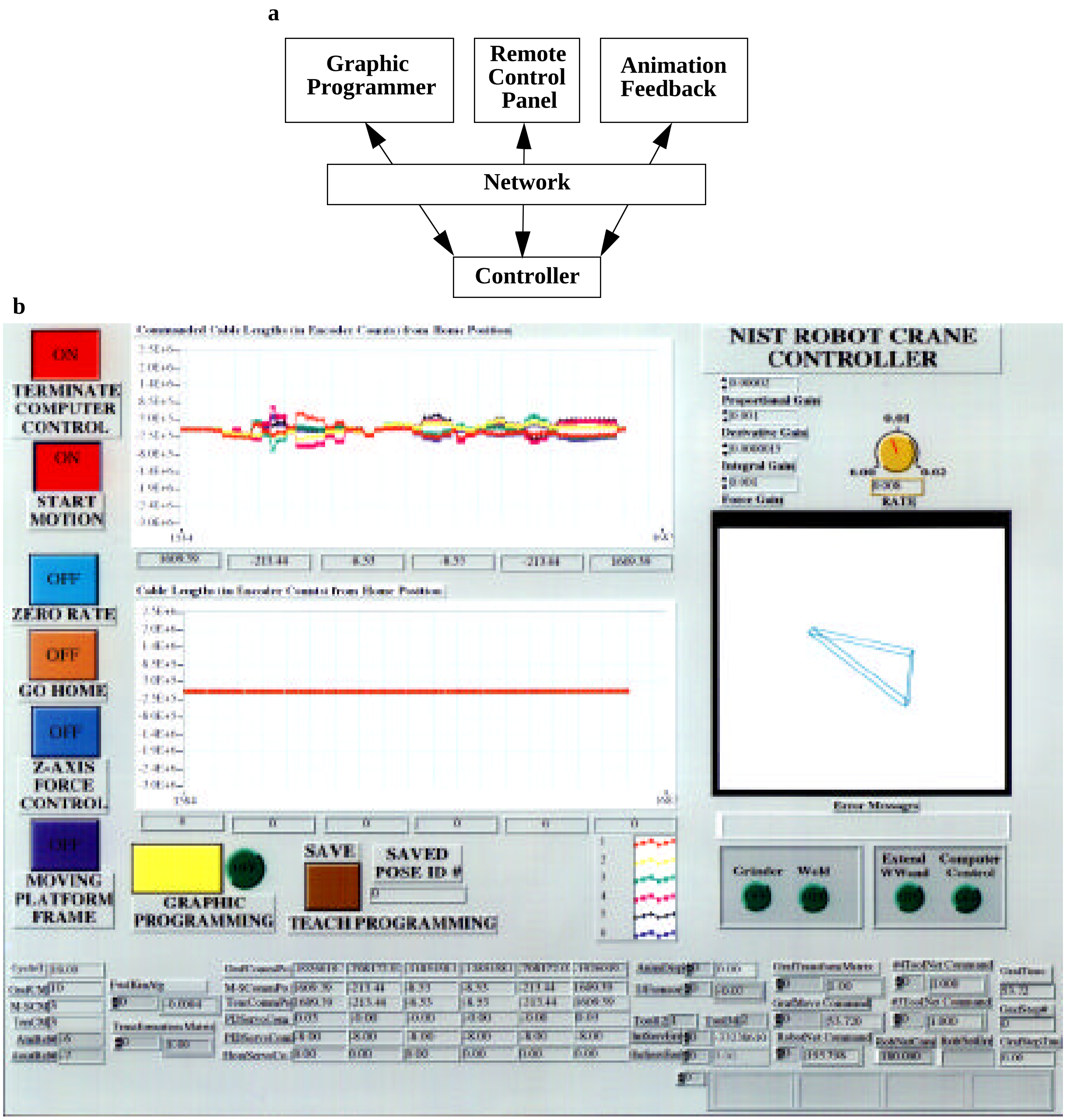
The mission of NIST is to improve the competitiveness of U.S. industry through the development of measurements, standards, and infrastructural technology. The goals of the NIST Intelligent Systems Division are to foster the development and implementation of advanced manufacturing systems, processes, and equipment, and to anticipate and address the needs of U.S. industry for the next generation of measurements and standards. The NIST Intelligent Systems Division conducts research and development efforts in a variety of intelligent machine projects, including: the Enhanced Machine Controller [6], and the RoboCrane Integration Testbed (RIT) Project. These projects are directed toward the development of open architecture control system standards for intelligent machine systems. The RIT Project is focused on large scale manufacturing industries and construction applications. The RoboCrane Integration Testbed utilizes the 6-Meter RoboCrane prototype to integrate open architecture controllers, sensors, tools, and equipment into a testbed for analysis and testing of potential standards and measurement techniques.

3.1 RoboCrane Control System

The RoboCrane control system [7] currently consists of the Controller, a Graphic Programmer, and a Remote Control Panel connected by a network. These modules are shown in the block diagram of Figure 2a. Various types of network interfaces have been developed and are being tested for the effective communication among these modules. In the near future a Head-up Remote Control Panel will be interfaced with the controller of a stereo vision system. Voice activation of control functions and an animation feedback will be also added.

The RoboCrane Control System was developed using commercially available Macintosh* hardware and software. It is capable of master-slave control (default mode) with one or two operators, graphic off-line control, "go home" capability, and manual teach control. Motion types available include single joint, TCP (Tool Center Point) Cartesian baseframe (default), TCP Cartesian frame, offset TCP Cartesian frame, constraint motions along vectors, rotations about vectors, and single axis force control.

FIGURE 2. a) RoboCrane Control System Block Diagram b) RoboCrane Control Panel



Since the operators of these controllers are not expected to be computer literate and might wear protective gloves, a simple and intuitive graphic interface for this controller was developed using LabView* software. Control modes and motion types can be activated or deactivated by computer mouse actions and/or touch screen actions, if a touch screen display is available. A typical version of this graphic control panel is shown in Figure 2b. It includes several families of graphic control and display tools. In its present form it includes Boolean control buttons which activate control modes and motion types, Boolean display lights which indicate the ON/OFF status of tools, scopes and strip charts which display time varying outputs, display or control dials, an animation window and an error messages window. The graphic display also includes a diagnostics section and a control parameters setting section. These sections are useful for troubleshooting and tuning the controller but will not be readily available in non-experimental versions of this controller. Important buttons, like the “START

MOTION” of Fig. 2b, display warning messages and allow the operator to change his mind when they are selected. Selection of any button will force the disappearance of any other buttons which are in conflict with it and could, if selected, create unsafe operating conditions.

The current version of the RoboCrane Control System includes a Graphic Programmer and a Remote Control Panel. The Graphic Programmer allows for the easy and safe generation of move commands and the timely movement and activation of tools. The Graphic Programmer runs on a Silicon Graphics* computer and controls the operation of a Deneb simulator and animator of the RoboCrane workspace three dimensional (3-D) solid model. While the operator animates any desired operations, the Graphic Programmer saves all the information relevant to the motion of the RoboCrane and the status of the various tools in a file. This file, together with information which describes the number of robot arms and tools, is then available through the network to any controller with the proper interface. When the “GRAPHIC PROGRAMMING” button is activated the proper files are located through the network and transferred to the controller. After a thorough data check (standard bit error correction procedure), the controller will proceed with the execution of the Graphic Programmer generated instructions, thus repeating the original actions generated by the operator. Since the files are available through the network, any robot or machine tool controller with this interface and file address information can be similarly controlled off-line. This information is stored in a standard text format and thus reading and interpreting it is easy. A Graphic Programmer like this can be used to generate the off-line control programs for a large number of robots and machine-tools. The Graphic Programmer structure is general and should allow its interface with other solid model simulators and animators of the workspace. Figure 3a shows a snapshot of a RoboCrane graphic programming operation. At this instant of the operation the grinder tool has been lowered and is cleaning the upper surface of an I-beam, in preparation for welding which will follow. A color change of the grinder indicates that the Graphic Programmer is generating code which notifies the Controller to turn the power of this tool ON.

FIGURE 3. a) RoboCrane Graphic Programming Snapshot, b) Animation Feedback frame from the RoboCrane Controller

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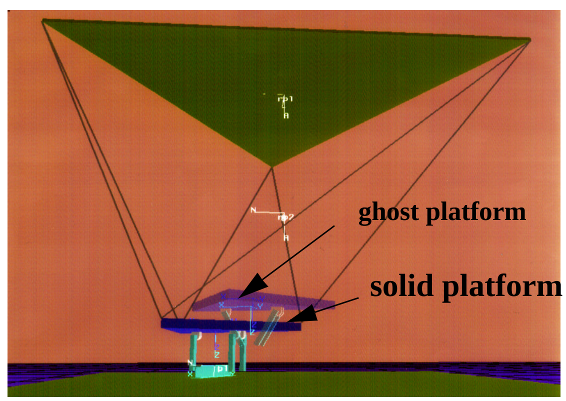
b



The Remote Control Panel is identical to that of the main Controller panel and is generated by a PC which is interfaced to the Controller through the network. In its default state it is a slave to the controller panel and displays the state of all its graphic tools. An extra button on the front panel allows the remote operator to become the master. If that is approved by the Controller, then the Controller settings can be set remotely, while the control panel of the actual controller has been reduced to a slave which simply displays the control settings selected by the remote operator. The remote control panel interface is now under development and testing but a significant portion is now working. There are several possible uses of the Remote Control Panel. The teach pendants of multiple operators can be equipped with the flat screen displays of laptop computers which will provide the same information and capabilities of the controller control panel display. A head-up operator display is already connected to the Remote Control Panel. Another possible application is remote trouble-shooting of the controller by the manufacturer or the supervising engineer. With this capability the plant manager can monitor the operation of each individual controller in his plant from his desktop computer or from thousand of miles away.

In the near future our Head-up Remote Control Panel will be interfaced with the controller of a stereo vision assembly. A sensor on the back of the unit can sense the orientation of the head of the operator. This information will be transmitted to the stereo vision assembly controller which will be commanded to follow the motions of the head of the operator, thus giving him a natural telepresence view of the work-space. With voice activation of the controller settings, master-slave operation will become easier and faster.

For those remote operation cases where the transmission of real time video of the work-space is not possible, or of good quality, we are developing the RoboCrane animation feedback interface. A simulation frame of animation feedback is shown in Figure 3b. The solid RoboCrane platform is located at the commanded pose, at a particular time instant, while the transparent (“ghost”) platform represents the current platform pose as it is determined by the controller position sensors. The information for the generation of this animation is provided by the controller to a Silicon Graphics* computer through the network. The “ghost” platform should always follow the solid platform while motion is taking place.

A telepresence system is currently being designed and integrated into the RIT. It will include a flexible manipulator attached to the work platform with a pan-tilt-vergence (PTV) head as an end-effector to the manipulator. NIST recently began a Cooperative Research and Development Agreement (CRADA) with Grey Pilgrim, Inc. to study their manipulator called EMMA (Easily Manipulated Mechanical Armatures) for this application and others.

Dual sets of stereo cameras (foveal and peripheral views) will be installed on the PTV head and allow a remote operator to have full RoboCrane work volume telepresence during operation. The operator will wear a head-up display for access to all modes and controls during RoboCrane operation.

3.1 RoboCrane Applications Studied

The applications for study on the RIT have included: grinding, gripping, sawing, welding, inspection, and peg insertion. As explained in the previous section, the control system has incorporated force and teleoperated control modes to allow an operator to perform grinding with smooth performance. Similarly, gripping, sawing and inspection have been performed using teleoperated modes with accuracies (including standard uncertainty) of 1mm in translation and angular rotations of 0.5° throughout a work volume of 100 m^3. And, open-loop/off-line control of grinding and welding have produced welds along a straight line with deviations of ±5mm (over 1 m) with no sensor feedback.

Future RIT work will include welding along contours and splines using sensor feedback. A heavy duty quick change will be integrated to allow for multi-control mode tool changing of the tools listed. The RoboCrane will therefore incorporate rapid tool change for performing multiple manufacturing tasks.

4.0 RoboCrane for Large Scale Manufacturing

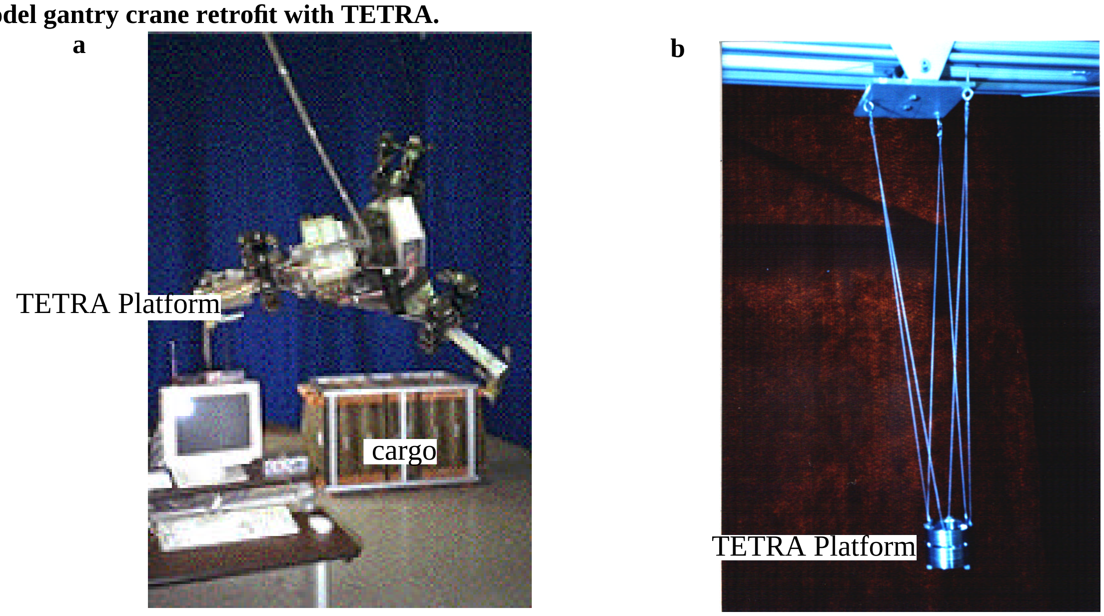
4.1 Manufacturing Facility (Internal) Retrofit with RoboCrane

4.1.1 Concept 1 - Bridge Gantry Crane Retrofit

Many manufacturing facilities have bridge gantry cranes incorporated into their building structure. These cranes provide heavy lift capabilities for material handling throughout the building and are often the main mode of transport for large, asymmetric loads in support of the manufacturing process. However, these cranes provide only vertical control of the cargo, allowing it to swing and spin freely during transport. A RoboCrane retrofit to existing bridge cranes would provide superior load stabilization [8] by using essentially controlled tag lines on the cargo at all times. The RoboCrane uses six computer controlled taglines (driven by synchronized winches) pulling in opposing directions to provide complete constraint of the cargo during transport, along with controlled maneuverability of the cargo during placement.

RoboCrane's multiple cable, synchronous control concept is currently being applied to bridge gantry cranes in the form of the TETRA - Suspended Cargo Acquisition and Stabilization System (TETRA: TETrahedral Robotic Apparatus). The TETRA system (see figure 4a) employs technology similar to the RoboCrane but is designed to augment existing lifting capabilities to facilitate teleoperative cargo acquisition and greatly improved cargo placement accuracy from much longer suspension depths (up to 50 meters).

FIGURE 4. a) Tetrahedral Robotic Apparatus (TETRA) Prototype shown pitched over cargo, b) 1/40th scale model gantry crane retrofit with TETRA.



The TETRA system achieves stability of suspended cargo in all six degrees of freedom by augmenting the bridge crane's single load bearing cable (which is already rated for the load) with up to six actively controlled stabilization winches and cables. These synchronized stabilization cables allow complete control over position and orientation of the hook *prior* to cargo acquisition and then restrains the cargo from swinging and spinning once it is lifted. TETRA's multiple cables essentially act as synchronized tag lines which automatically react to the operator's control inputs to the crane. NIST has built a prototype TETRA system in it's high-bay facility, which has demonstrated superior cargo stabilization at suspension depths of up to 25 m (the limiting height of the facility). At these large suspension depths, initial stability tests showed no more than 10 cm to 15 cm of horizontal cargo sway during crane acceleration and stopping. Spinning of the cargo was almost non existent. Current efforts include: performing rigorous load stability experiments, integrating the existing RoboCrane controller to perform teleoperative cargo acquisition and placement tasks using visual tracking, and demonstrating TETRA stow capabilities, allowing conventional lifting techniques to be employed if so desired. A typical gantry crane retrofit with TETRA would look similar to the model shown in figure 4b.

4.1.2 Concept 2 - Facility Supported RoboCrane

Similar to the bridge gantry crane retrofit, attaching pulley blocks to the manufacturing facility structure (i.e. building girders and/or main beams), can allow a facility not including a crane to incorporate a RoboCrane and the functions it can provide. Winches can be attached to the ground, support structure, or reside on the platform.

Multiple RoboCranes (TETRA's) are possible to provide multiple tools controlled simultaneously, or even combined to work on the same work piece, such as an airplane or as a flexible fixturing set-up while, for example another RoboCrane welds the piece. This system can therefore, provide large work volume control. Applications for this Robocrane concept are limited to the building support structure loading. Low facility height can limit Robocrane work volume to low levels as determined by the support structure, maximum cable strengths, and maximum winch line pull.

Mobile gantry cranes can also provide the necessary support structure for the RoboCrane work platform while allowing mobility over a large work area. Therefore the mobile gantry, supporting a RoboCrane, can facilitate mobile manufacturing, such as: flexible fixturing, material handling, and tool control, with accurate results. The typical mobile gantry is rectangular but the RoboCrane is not limited to this shape (see figure 1). An octahedral shaped gantry incorporates support members that are in nearly pure compression and tension except for self weight, and provides the lightest possible gantry supported RoboCrane configuration.

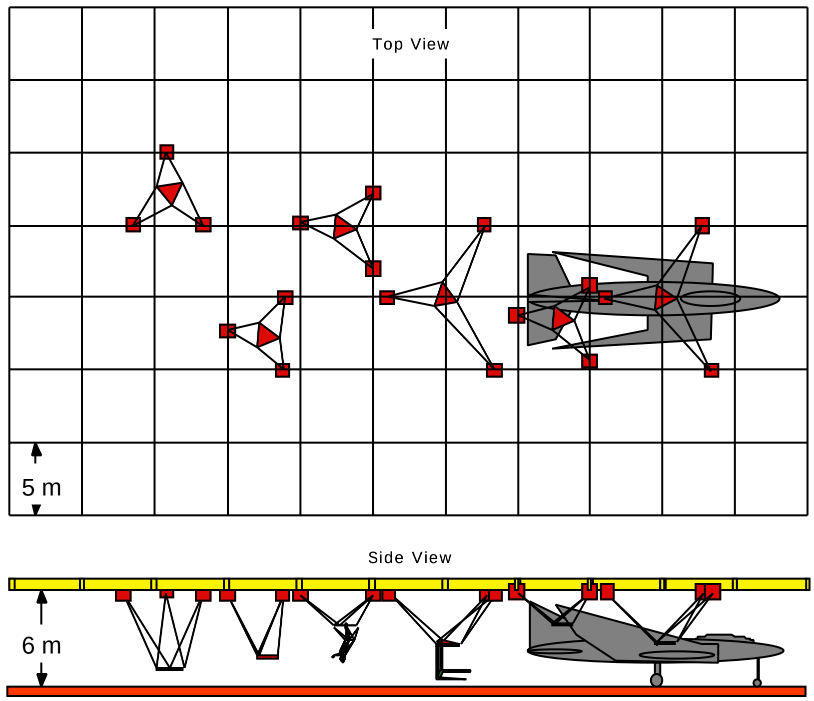
4.1.3 Concept 3- Grid Supported RoboCranes

In a military scenario, combat aircraft frequently require munitions loaded, avionics modules replaced, and other servicing and repair tasks. Many of these tasks involve lifting, manipulation, and accurate positioning of heavy objects. Under combat conditions, there is a premium on speed, reliability, and precision.

A RoboCrane can be configured within a hanger facility by suspending three winch carriages, each with two winches, from a grid of tracks on the hanger deck ceiling. A triangular work platform suspended from three winch carriages constitutes a RoboCrane that can maneuver into position over aircraft to quickly and precisely manipulate heavy objects such as munitions, avionics packages, and even engines and structural components. This configuration can not only provide simultaneous RoboCrane activities, but provides a small scale RoboCrane (as compared to Concept 2) that is transportable throughout the facility and reconfigurable dependent upon access, tasks, and kinematic constraints.

Figure 5 shows top and side views of six RoboCranes with winch carriages in a variety of positions. The figure illustrates how the RoboCrane would maneuver on a grid of tracks on the ceiling of the hanger. The winch carriages move independently but cooperatively under computer control. Each winch carriage could also be operated independently and separately as a conventional hoisting device. Each of the RoboCranes can manipulate tools, grippers, and a variety of specialized lifting devices that can manipulate heavy objects over and under wings and fuselages.

FIGURE 5. Top and Side Views of Grid Support RoboCranes

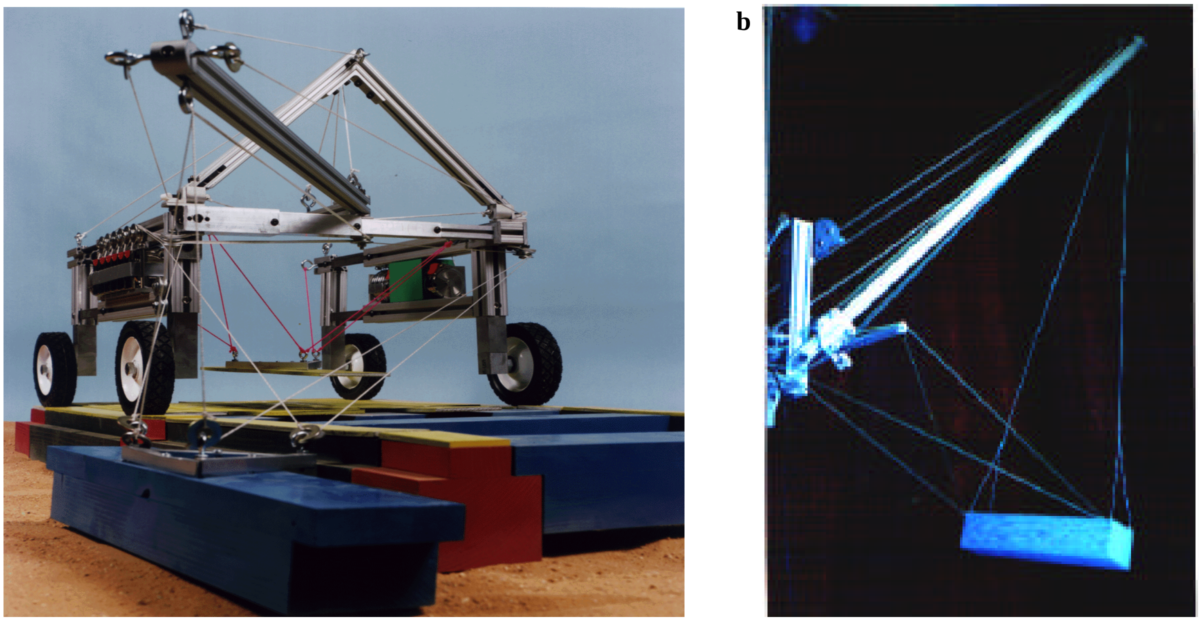


4.2 RoboCrane Retrofit to Conventional (External) Cranes

While fixed support structures such as buildings and internal cranes can support a RoboCrane for doing manufacturing activities, conventional "external" cranes, such as: mobile gantry, boom, tower, port, etc. cranes can also be used. Mobile gantry cranes typically support loads internal to the structure but the structure can also provide the counterweight for cantilevered loads external to the structure. This not only provides a larger work volume but provides access to loads that are beyond the internal hook reach. Furthermore, a RoboCrane support point can be placed external to the structure and provide the same constrained work platform operation capability as other RoboCrane configurations but, over a larger work volume. Figure 6a shows this RoboCrane configuration, modeled as an Air Transportable Expeditionary Crane (ATEC) in a US Marine Corps. raised airstrip assembly application [9] while figure 6b shows a boom crane model retrofit with a RoboCrane cable configuration. Many more applications of the external RoboCrane mobile gantry crane retrofit are possible with the controlled work platform, even while performing simultaneous internal structure RoboCrane operations (also shown in figure 4a).

FIGURE 6. a) Air Transportable Expeditionary Crane Model fabricating a raised airstrip. Note dual RoboCranes working simultaneously. b) 1/16th scale Boom Crane Model with RoboCrane Cable Configuration to Constrain Load.

a b



4.3 Examples of Large Scale Manufacturing using (External) RoboCranes

4.3.1 Bridge Construction

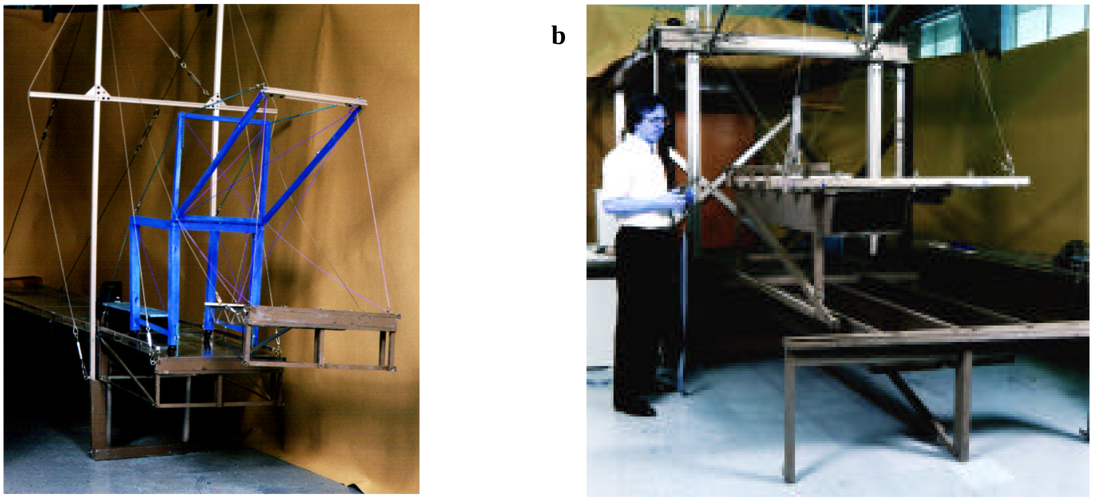
For crane applications such as bridge construction and infrastructure maintenance, the RoboCrane provides rapid deployment/retrieval of bridge truss elements, and deck plates. The RoboCrane, as shown in figure 7a, has been designed and modeled to provide a lightweight system that rides on the partially constructed bridge and provides load maneuverability via multiple control modes. Teleoperative control has been demonstrated with a 1/6th scale model (see figure 7b).

The crane carries no counterweight since it is attached to the bridge directly and provides a stable system for rapid bridge component assembly and section launch. Hence, the crane is light enough to ride on the bridge and provides potential markets for crane manufacturers in the highway and port construction industries. Typically, technology existing today includes heavy (counterweighted) cranes maneuvering bridge components in a slower and more labor intensive scenario. Alternative RoboCrane support structures (conventional cranes) will suffice to deploy the RoboCrane, such as: boom, truck and/or tower cranes, but are typically heavier and may not be able to ride on the bridge being constructed.

Similar to the no-counterweight crane-to-bridge truss cables, is the cable-stayed design for cantilevering bridge sections over highways, wetlands, and other non-support areas where bridge foundations cannot be constructed. The design consists of a dual tower located on two ground supports for the bridge. Truss cables connect from a counterweight or other existing bridge sections, over the cable-stay and down to the bridge truss section to cantilever it from the previous bridge section. Up to 52 m of bridge sections can be cantilevered, including the construction crane and material handling truck, before reaching the next set of ground supports.

FIGURE 7. a) 1/16th Scale Model Bridge Construction RoboCrane b) 1/6th Scale Model Bridge Construction RoboCrane Performing Bridge Section Launch Using Teleoperated Control.

a b



4.3.2 Residential/Commercial Construction

Similar to the bridge construction RoboCrane method, residential and commercial building construction can improve performance of current crane control for installing: walls, equipment, and roof assemblies; flexible fixturing of walls, tools, and equipment; and general pick and place operations with much greater control and precision placement of loads. Through a Cooperative Research and Development Agreement (CRADA) with Lehigh University's ATLSS (Advanced Testing of Large Scale Structures) Center, NIST and Lehigh are developing methods to robotically install entire structural floor assemblies for low to high rise buildings that are preassembled on the ground. This can greatly reduce construction worker accidents from falls, etc. The operator could control a RoboCrane attached to a conventional crane to precisely maneuver entire structural floor assemblies, with six degree-of-freedom control, by using teleoperation or hybrid modes. Connections to vertical supports are accomplished via patented Lehigh ATLSS Connectors.

4.3.3 Ship Construction

Ship construction provides another large scale manufacturing application that can benefit from the use of a RoboCrane retrofit to existing conventional equipment. As part of the work for DARPA, the full scale prototype RoboCrane model supported a cantilevered beam support from a RoboCrane cable configuration and supported a payload of 2270 kg[10]. The simulated payload demonstrated the ability of the RoboCrane to support an end-effector such as a robot arm holding a welder to produce welds inside a ship's hull. The integration of the boom and RoboCrane system onto an existing tower crane, for example, could increase the functionality of the crane into a large scale manufacturing arena supporting large end-effectors and tools.

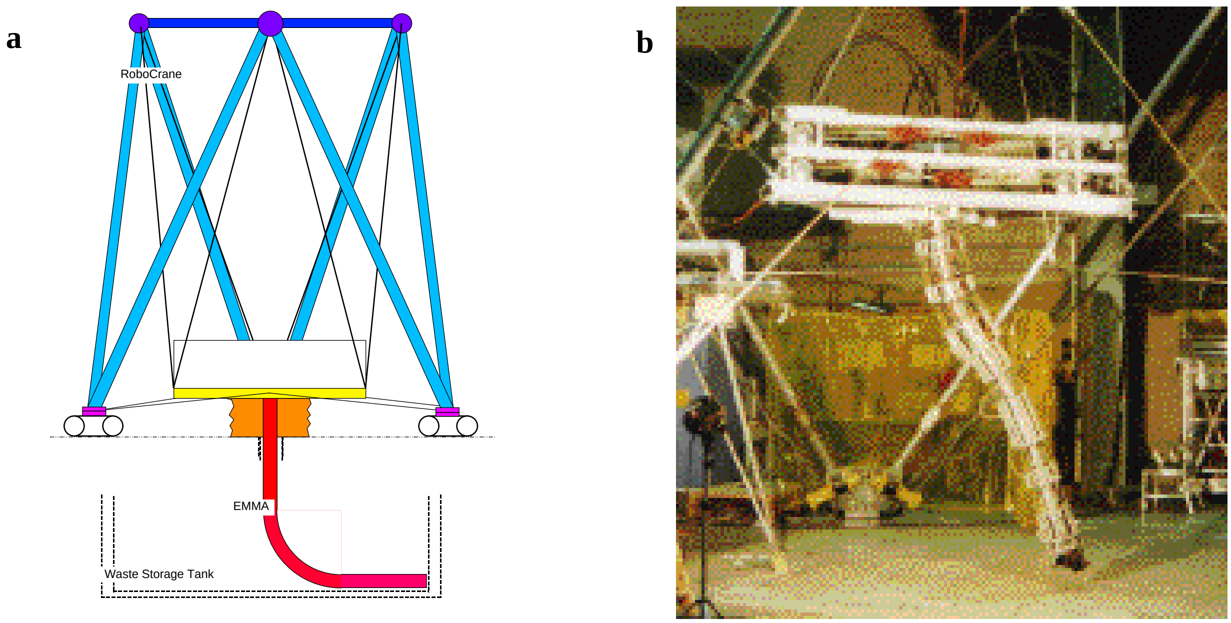
5.0 Other RoboCrane Unmanned Ground Applications

Many other potential unmanned ground applications incorporating the RoboCrane have been studied. They include waste storage tank remediation and buried waste or munitions retrieval. In these two applications, target points for placing/retrieving loads are straddled with mobile gantry cranes or reached by cantilevering with a boom or tower crane.

5.1 Waste Storage Tank Remediation

Waste storage tank remediation has been a preliminary driver for studying large structural support of a RoboCrane work platform deploying a Long Range Manipulator. The Department of Energy has more than 170 waste storage tanks in the Hanford, Washington tank facility that are in need of remediation. Although manufacturing is not a part of this application, the RoboCrane provides a viable solution to this problem, as well. NIST recently began a CRADA with Grey Pilgrim, Inc. to study the concept of a RoboCrane deploying a serpentine style manipulator, called EMMA (Easily Manipulated Mechanical Armatures), into a waste storage tank for inspection and remediation of high level radio active waste (see figure 8 a). A 30 m tall by 25 m diameter RoboCrane can deploy a 25 m long EMMA into the tank from any riser location on the tank so that no or little modification to the tank is necessary. A 1/4 scale prototype has been integrated as part of the RIT (see figure 8b).

FIGURE 8. a) Waste storage tank remediation concept using RoboCrane and EMMA, b) 6 Meter RoboCrane suspending an EMMA to study waste storage tank remediation applications.



By using a RoboCrane instead of a conventional gantry, a multitude of advantages are evident:

- minimal ground loading
- no tank loading
- large work volume
- flexible gantry for mobility over uneven terrain
- precise manipulator control
- field system deployment
- heavy duty work platform to support tools, manipulators, equipment, and systems

Estimated work platform accuracy for this system is ±3 mm translation and ±0.5° angular rotation. Stiffness is estimated at approximately 2 kg/mm laterally and 2700 N•m torque. The RoboCrane also provides an excellent shroud structure for containment of waste particles. It can provide motion for the entire system, including the RoboCrane, EMMA, clean-room, etc. from one tank to another tank. Therefore, rapid system deployment can speed operations and reduce remediation costs.

5.2 Buried Waste, Munitions Recovery

Buried waste, including munitions recovery, is another area whereby the RoboCrane has potential application. Buried nuclear waste is leaking at various sites around the U.S., leading to increased continment zone volumes. Therefore, waste remediation of these sites is necessary for: waste containment and/or uncovering buried waste, and for removing the waste and repackaging it into manageable containment for storage. The RoboCrane provides an excellent means of straddling or cantilevering over these sites and remotely performing tests with sensor packages, digging, removing waste, and placing the waste into containers. The work platform can support tools (saws, grippers, diggers, drills), equipment (sensors packages, waste conveyors) and manipulators (such as the Grey Pilgrim EMMA), to gently and precisely uncover waste.   Accuracy and resolution are dependent upon the waste site size, desired configuration, and accessibility.

Munitions recovery also requires precise, remote operation and non-ground contact in the target area. Unexploded ordnance are a pervasive hazard throughout the world. The RoboCrane work platform supporting sensor systems, equipment and tools can remote the operator and still provide the similar digging, removal, and transport of munitions as in the buried waste application.

In both the buried waste and munitions recovery applications, the RoboCrane can provide remote 6 DoF work platform control over large work volumes through retrofit of existing cranes or with a lighter octahedral configuration.

6.0 Summary and Conclusions

The RoboCrane Integration Testbed Project is an ongoing research and development project that has consistently brought out new ideas for enhancements and/or replacement of existing methods of large scale manufacturing. Cranes are an integral part of large scale manufacturing and can be improved upon for increased efficiency, performance, and functionality. Load stabilization and control using RoboCrane technology could dramatically improve load acquisition, transfer and placement speeds. It would also improve operational safety and therefore the cranes overall cost effectiveness. We believe that several industrial applications could immediately benefit from this technology. For instance, material handling, tool manipulation, remotely controlled nuclear/toxic waste cargo handling, large aircraft assembly/refurbishment, and automated palletized inventory (stacking/retrieval) management.

An advanced RoboCrane controller has been developed. The graphic off-line control capability of this controller makes programming of numerous controllers easy and fast. A remote control panel allows monitoring and troubleshooting of numerous controllers from remote locations. In the future the remote head-up display, voice activation of control functions, animation feedback, and telepresence will make master-slave control easier and faster. Telepresence remote control will allow increased work platform maneuverability during hazardous operations

Cable configurations have been and will be studied at NIST to provide load control as loads are suspended from a variety of structures. Ongoing control system efforts enhancing the RIT will also provide high level control functionality. We hope the use of the control techniques and interfaces developed for this testbed will contribute to the significant advancement of intelligent machines in the future.

7.0 References

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