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Summary of Modeling and Simulation for NIST RoboCrane® Applications

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Abstract

The Intelligent Systems Division (ISD) at the National Institute of Standards and Technology has been using modeling and simulation and software for conceptual design and prototyping of advanced robotic cranes. RoboCrane® concepts have been developed for various applications, such as military ISO-container handlers on land and sea, large-scale welding and gripping, and nuclear waste remediation. The capability to develop our models in an advanced solid modeler and convert them into moving, controlled designs is critical to achieve the level of confidence that is required before building a full-scale prototype. Although we do have scaled-prototypes of some of our designs, the computer model, controlled with simulation programming and developed from imported solid models, offers a good way for sponsors to see the concepts and capabilities of the RoboCrane® systems. This overview paper summarizes the efforts of ISD in developing the RoboCrane® simulations and the important role simulation and modeling tools have within our projects.

Keywords:

simulation, computer-aided-design, solid modeling, graphic programming, conceptual design, robotic cranes, RoboCrane®, operator interface

Introduction

The Intelligent Systems Division (ISD) within the Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) moved from simple 2D/limited 3D drafting tools to more advanced 3D design and analysis tools in the mid 90's. A good example of one of the complex 2D/limited 3D designs and a resultant prototype was the Drum Grabber as shown in Figure 1.

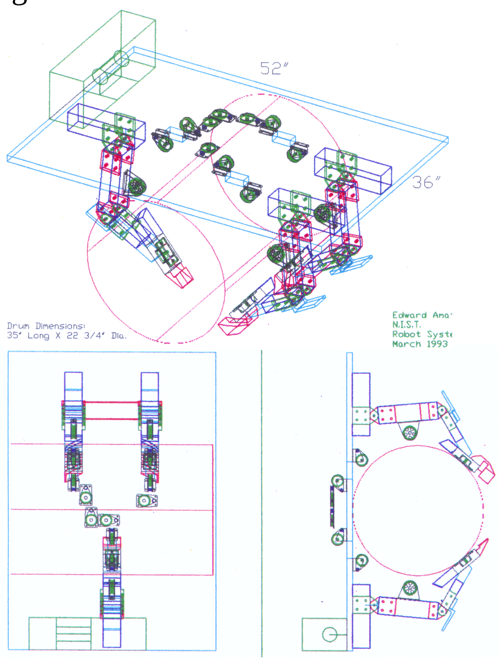

Figure 1. Drum Grabber design model as an example of limited 3D renderings before advanced solid modeling was available.

This design from early 1993 was a complex three-arm device to move 55-gallon drums. The design process was a trial and error attempt to understand the 3D shape of the drum and the interactions of different grabber end-effector configurations with the drum. This design process strained the capabilities of one of the leading 3D tools then available on a personal computer. These 3D tools, typically developed from a 2D drafting application, were limited and difficult to use. Obviously, we needed better tools and systems for more efficient and economical computer aided design (CAD).

The Drum Grabber was built and successfully demonstrated as shown in Figure 2. But, a 3D model and simulation with Pro/Engineer[1] working with Teleoperative Graphical Robot Instruction Program (TGRIP) would have more effectively identified the limitations of the final prototype. This would have led to a more refined solution for the project using less time, effort, and money.

[1] The National Institute of Standards and Technology (NIST) does not endorse the products mentioned in this paper. These products are used for illustration purposes only and are not mentioned because they are better than another similiar product.

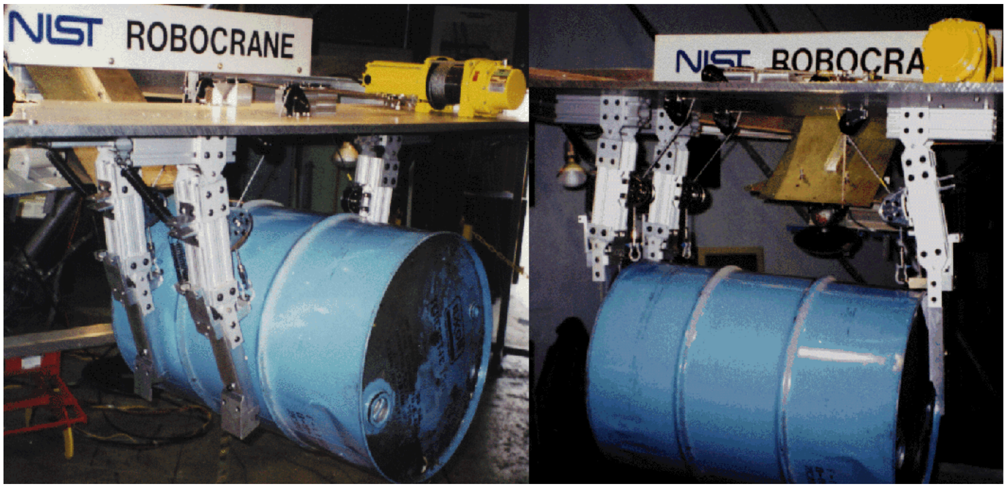

Figure 2. The Drum Grabber attached to the RoboCrane® work platform

Now, the conceptual design process for intelligent systems and , specifically, advanced robotic cranes has been improving with the availability of more competent simulation and modeling software. These are not just good independent systems, but are best used with similar software packages. For example, a good solid modeling system with power to quickly and easily generate complex assemblies working with a simulation or analysis package form a good complementary set of tools. This overview also details the researchers' efforts to simulate the conceptual designs before and usually instead of constructing costly prototypes for the RoboCrane® projects. In addition, we have used simulation capabilities of these solid modeling systems to develop an operator interface displaying a 3-D model of the moving platform. The model provides visual cues for the operator to detect collisions, platform location and pose, as well as other aspects before and during the platform moves.

NIST RoboCrane® Background

The NIST RoboCrane® effort began in 1988, "to develop kinematically constrained, dynamically stabilized robot cranes capable of lifting, moving, and positioning heavy loads over large volumes, capable of supporting fabrication tools and the inspection of large size difficult to reach structures"[1]. As this development evolved, a new class of advanced robotic cranes, based on the Stewart mechanism principle of replacing rigid struts with wire cables, was created. Figure 3 shows the current RoboCrane® testbed configuration[2]. This 6-meter robotic crane has six cables controlled by six winches at the bottom vertices of a octahedral gantry[3]. The six cables act as computer-controlled taglines and eliminate the typical sway that is associated with loads moved using conventional crane equipment. The cables span from winches, up and over pulleys, and back down to the suspended triangular (work) platform. The work platform supports appropriate tools and mechanisms depending on the unique application. Because the platform is constrained in six degrees-of-freedom, it can control tools for large-scale manufacturing, military, and construction tasks.

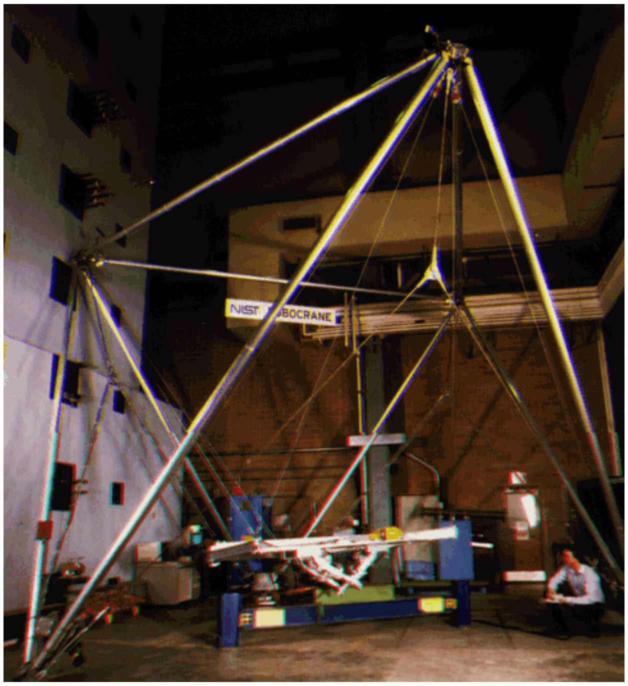

Figure 3. The 6 Meter RoboCrane® Integration Testbed

RoboCrane® projects address a variety of applications. These projects are all based on the original 6 meter RoboCrane® (now part of the RoboCrane® Integration Testbed), but have redesigned support structures and cable configurations that provide tool and equipment manipulation without adding unnecessary weight to the support structure.

To demonstrate unique RoboCrane® applications to our sponsors, we use quality modeling and simulation tools which play a major role. The expense of developing full-size prototypes is prohibitive for NIST and most large-scale manufacturing, military, and construction research and development efforts. But, we can demonstrate the concepts with computer generated solid models and simulations. We then build physical scale models to further understand and modify the design. Because of the quick development times offered by 3D visualization of RoboCrane® concepts through modeling and simulation, we now develop better designs with less re-work of the physical models.

In addition to 3D modeling and simulation, the RoboCrane® Integration Testbed is a testbed for the Real-Time Control System (RCS) reference model architecture[4]. Development and testing of this hierarchical control architecture on the RoboCrane® helps us quickly adapt to other intelligent system applications. Many RoboCrane® applications are challenging control situations which, in turn, help RCS mature into a more robust and generic system. RCS systems require an operator interface. By using TGRIP and other simulation software, graphical operator interfaces are developed with the power of advanced graphics and visual cues.

Simulation of RoboCrane® Applications

Air Transportable Expeditionary Crane (ATEC)

The Air Transportable Expeditionary Crane (ATEC) was developed using RoboCrane® technology as an advanced concept in multi-purpose military equipment for the U.S. Marines. The ATEC is designed for air transportability, to self-assemble, and to perform multiple military tasks such as: container handling, raised runway construction, tree clearing, and flexible fixturing of heavy machinery (e.g., tank repair). This is an example of the RoboCrane® adapting to a conventional gantry crane[5]. Initial concepts of a mobile gantry crane were developed in a solid modeling package as shown in Figure 4.

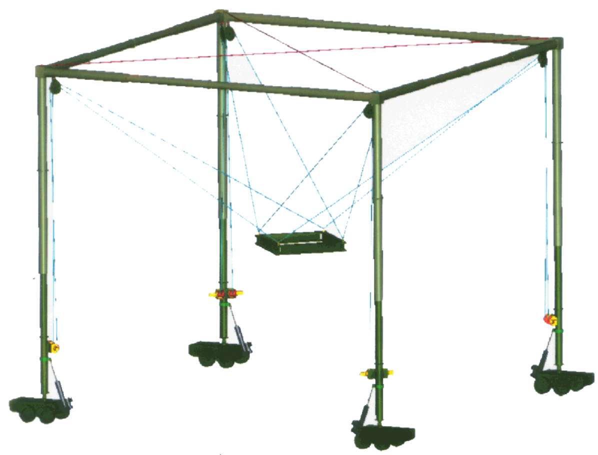

Figure 4. ATEC 3D Solid Model developed using Pro/Engineer Solid Modeling Software

Using the 3D solid model and physical scale models, various joint designs and decisions on the mechanical structure were made. The solid models gave static views of the working volume and comparative, component analysis for a preliminary mechanical design. After design of the conceptual components, a simulation model which demonstrated the proposed system capabilities was developed in TGRIP (Figure 5). The simulation shows (1) how the crane platform moves and operates, (2) how a raised airstrip is assembled, and (3) how related components interact on the construction site. Using the model, actual construction sequences may be planned and changed to easily determine the optimum assembly sequence. This is especially important to the U.S. Marine Corps since time is critical in the construction of an airfield during military operations.

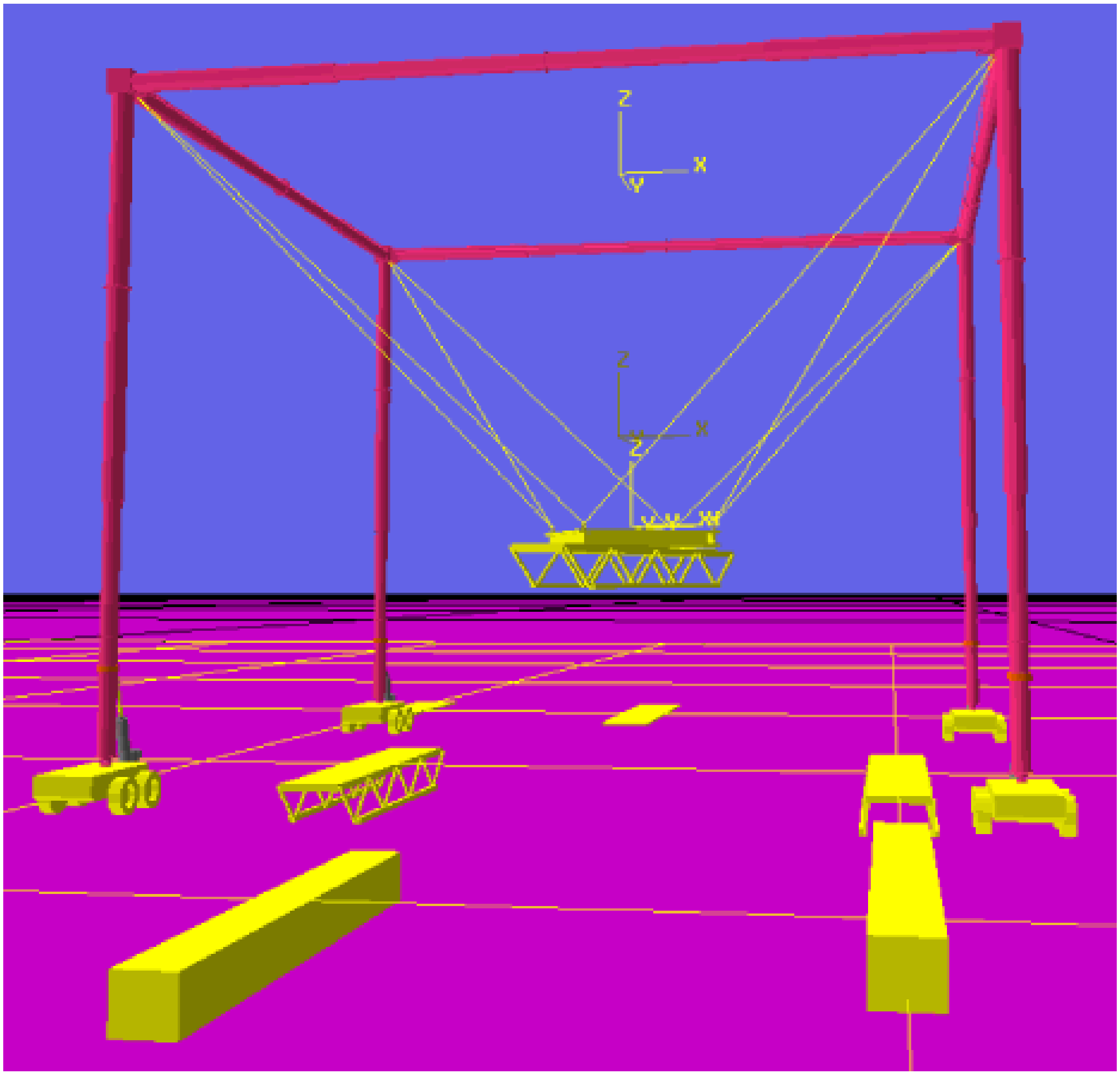

Figure 5. TGRIP Simulation snapshot showing the ATEC assembling raised airstrip components

Mobile Offshore Base Crane

The Mobile Offshore Base (MOB) crane is an application that applies RoboCrane® capabilities to a U. S. Navy concept for a mobile offshore platform and airstrip. The rail crane required for the platform has the difficult duty of off-loading container vessels in sea states up to 3 (e.g., ± 1 meter wave amplitudes at periods of 5 seconds). The conceptual design and simulation were critical to explain to the sponsor how the RoboCrane® work platform would interact with a cargo ship in random motion while off-loading standard containers. Figure 6 shows two TGRIP simulation snapshots. The 3D modeling and simulation of the MOB crane concept was especially challenging because both the dual RoboCrane® platforms (12 Degrees-of-Freedom (DOF)) and the ship 6 DOF motions needed to be syncronized. TGRIP was also used to simulate the MOB transportation system which carries cargo containers from the robot crane system and to storage compartments. The part geometries used in the simulation were pre-drawn with the Pro/Engineer modeling software and then imported into TGRIP. Graphic Simulation Language (GSL) programs were used to control the motions of the robot crane system and the transportation system.

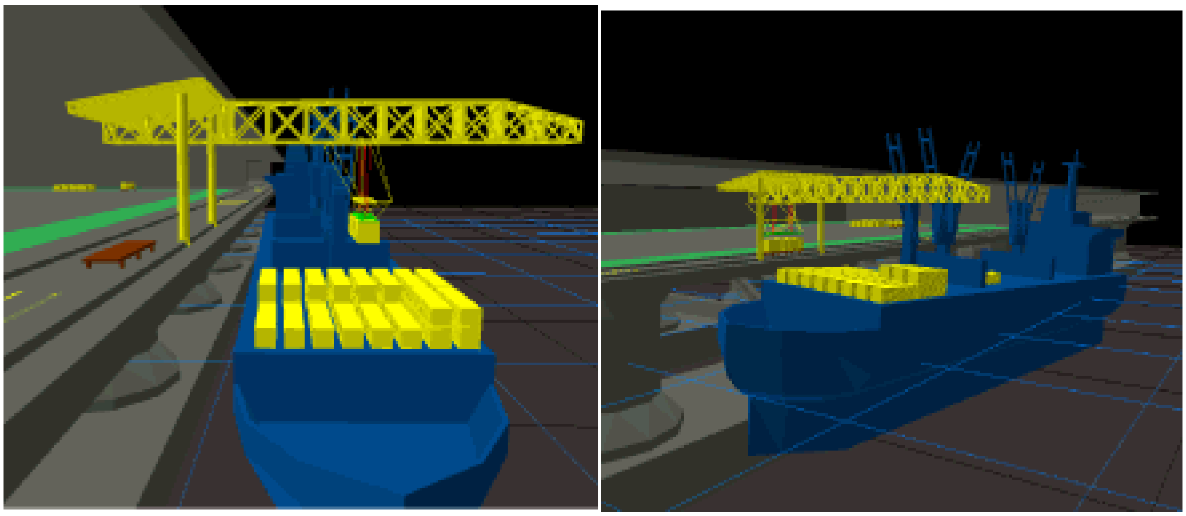

Figure 6. TGRIP Simulation snapshots of the MOB crane off-loading a container ship berthed along the MOB.

RoboCrane® Integration Testbed

RoboCrane® Testbed Graphical Programming

The graphical programming and animation of serial manipulators is straightforward with most commercially-available software packages. That is not the case with experimental manipulators that have no serial mechanism design. In [6], a graphic representation technique which solves that problem is described. The technique involves breaking the mechanism into a tool plate and several serial manipulators which can be handled by the available software packages. The tool plate is commanded by an operator to perform the desired robot motions and operations, while the motion of the serial manipulators is orchestrated to follow the motions of the tool plate. The operator, using any 3D simulation package, moves the tool plate to the desired pose. As long as the coordinates are with respect to the workcell baseframe and the interface data files are in text format, the controller interpreter will understand them and command the proper actuator moves. In the case of the RoboCrane®, the moving platform moves like a free, rigid body in 3D space. The cables are represented by 3 DOF manipulators mounted on the reference platform or simple datum lines which follow the vertices of the moving platform. Figure 7 shows a TGRIP representation of the RoboCrane® in a building construction demonstration workcell.

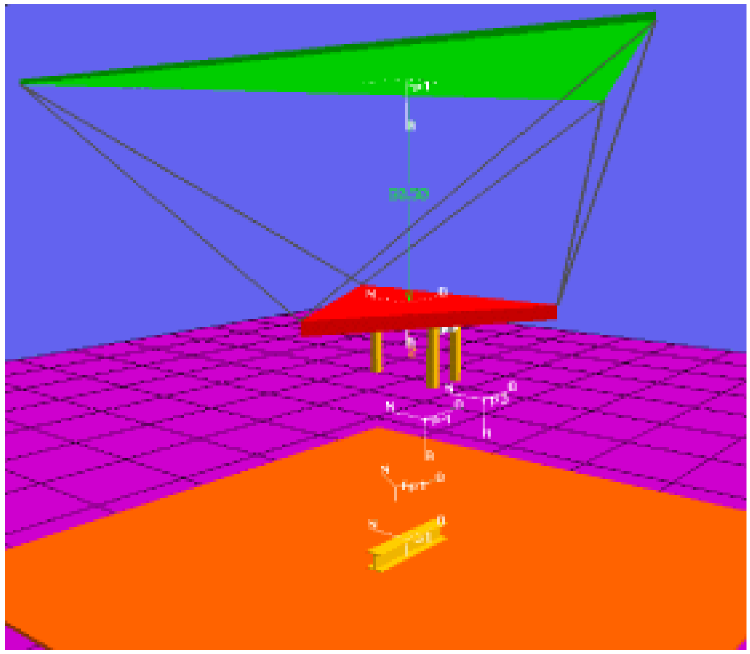

Figure 7. TGRIP Simulation Snapshot of the RoboCrane® Integration Testbed showing the suspended work platform with a gripper ready to grab an I-beam.

RoboCrane® Welding Off-Line Programming

The RoboCrane® Integration Testbed has demonstrated various tooling and equipment such as a grinder, saw, gripper, manipulator, and welder. One of the tests conducted was a demonstration of continuous arc welding. This demonstration was significant because it showed the operator interface and off-line programming capabilities of the RoboCrane® while performing a precise manufacturing task. This has been the most challenging application of the remote graphic programming capabilities that we have tested to date. The TGRIP animator of the RoboCrane® model was used to generate the necessary commands for the actual RoboCrane® work platform motions in coordination with a grinding and a welding tool. The grinding tool is first used to clean the surfaces which are about to be welded. The welding tool generates tack welds at strategic locations to prevent thermal stress deformation and then proceeds with bead welding. Figure 8 shows the animation of the grinding operation of two beams which are about to be welded. More details of the off-line programming interface and the demonstration are provided in [7]. Figure 9 shows the controller graphic interface panel which was designed for this application. Graphic display tools inform the operator about the status of the moving platform and the various tools mounted on it.

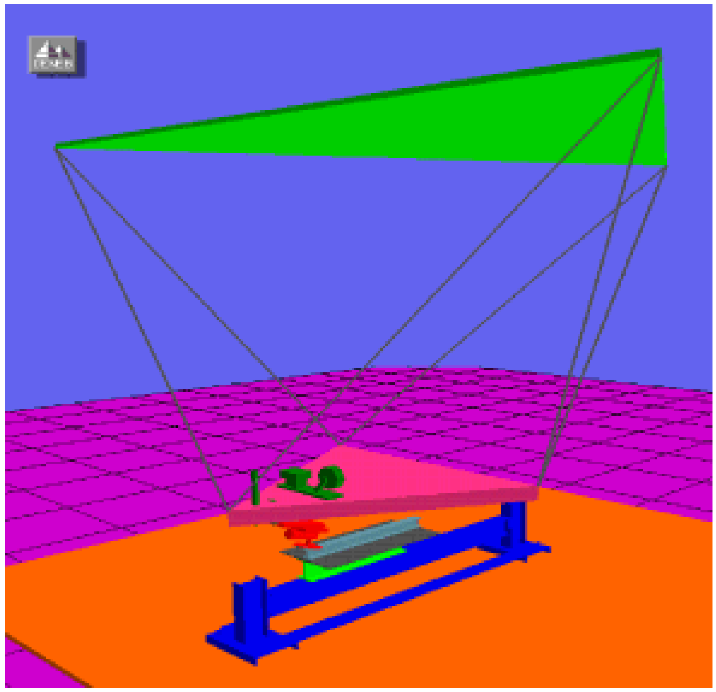

Figure 8. TGRIP Simulation Snapshot of the RoboCrane® performing grinding prior to welding during an Off-Line Program. The generated file from the simulation is retrieved by the controller for execution of the grinding and welding tasks.

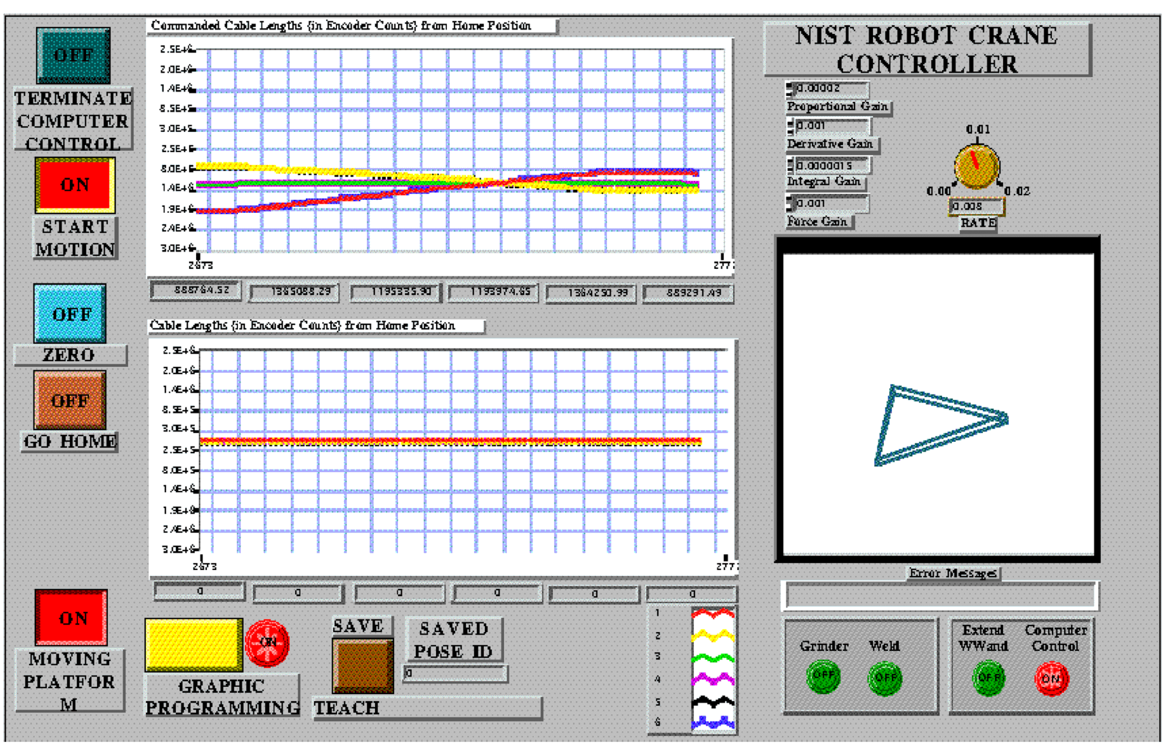

Figure 9. RoboCrane® Controller Graphical User Interface Panel Image with touch screen, mode and gain selects, and diagnostic and graphical feedbacks.

RoboCrane® Bridge Construction

RoboCrane® is a potential solution for problems in automated and efficient bridge construction [8]. This solution is a blend of state-of-the-art RoboCrane® technology and commercially available cranes that together provide a safe, lightweight, easy-to-use, and rapid method for highway bridge construction and maintenance. A commercial mobile gantry crane is modified with a boom, vertical stay, and the RoboCrane® cable configuration and controller. This combination provides cantilevered bridge components and assemblies to be precisely positioned with intuitive joystick control to build a bridge in front of the crane. Modular bridge components for military and commercial applications are available. These can be assembled using this RoboCrane® system. To demonstrate the capabilities of such a system, we created a working scale model and a TGRIP simulation (see Figure 10). This simulation sequenced the assembly and placement of a set of modular bridge components. By using and modifying previously designed graphic models, the bridge application was modeled quickly. Again, GSL programming was used to control the motions of the RoboCrane® platform and to animate the simulation components.

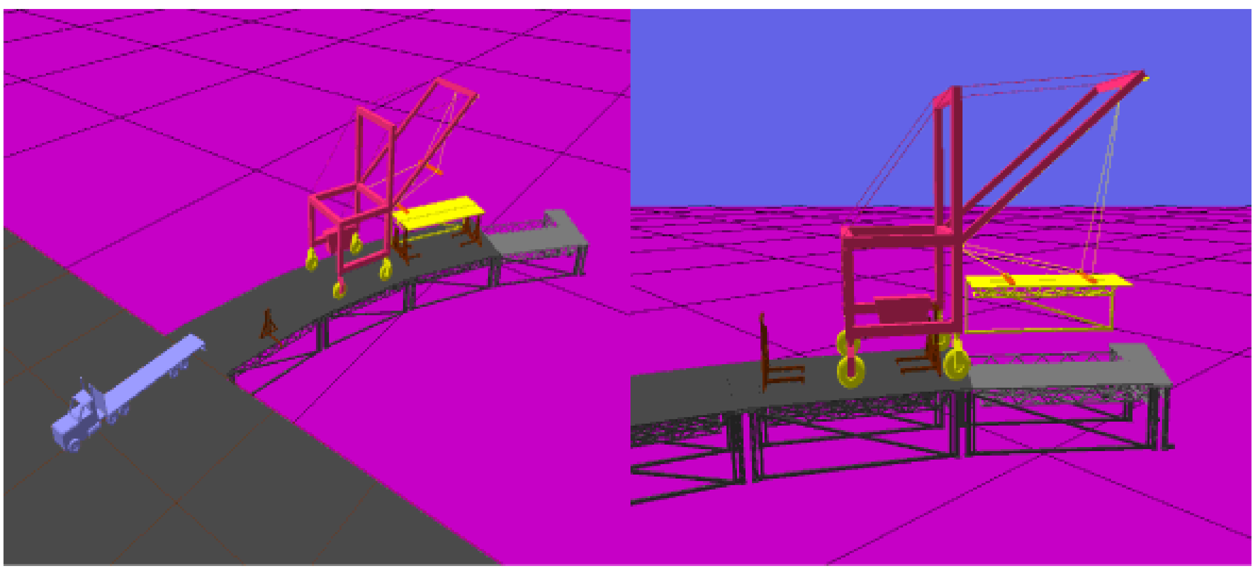

Figure 10. TGRIP Simulation Snapshopts showing the RoboCrane® Bridge Construction Concept

Waste Storage Tank Remediation Concept Simulation

One of the most recent applications employing RoboCrane® technology has been in nuclear waste remediation. The NIST RoboCrane® deploying Grey Pilgrim's EMMA (Easily Manipulated Mechanical Armatures) is currently being studied as a concept for waste storage tank inspection and remediation of high-level radioactive waste. "When combining the RoboCrane® and EMMA, the result is a stable work platform, or base, on which the EMMA can exert forces and torques necessary to achieve tank remediation. EMMA actuators (winches or linear actuators), amplifiers, load cells, and sensor interface will be mounted on the

RoboCrane® work platform above the tank and therefore, away from high radiation levels. The work platform can position the EMMA precisely into the tank while allowing for nonvertical risers" [9].

The modeling and simulation of this system began by developing a detailed solid model of the RoboCrane® system and additional models needed for the site simulation. Figure 11 shows the RoboCrane® system modeled in Pro/Engineer. After detailed modeling and design adjustment, this model was directly imported into TGRIP to be used in the simulation. An iterative process between the solid modeler and the simulation resulted and ,therefore, improved the design. We also used some existing EMMA simulation models developed by Pacific Northwestern National Labs (PNNL) in an early phase of the tank remediation concept. PNNL's simulation of EMMA was joined with NIST's simulation of the RoboCrane® system. The ease of combining all existing design and simulation efforts from various sources into TGRIP was helpful. The simulation used 3D solid models and GSL programming to make the design come to life. Figure 12 shows a snapshot from the Waste Storage Tank Remediation Concept simulation which was used to demonstrate the concept to sponsors.

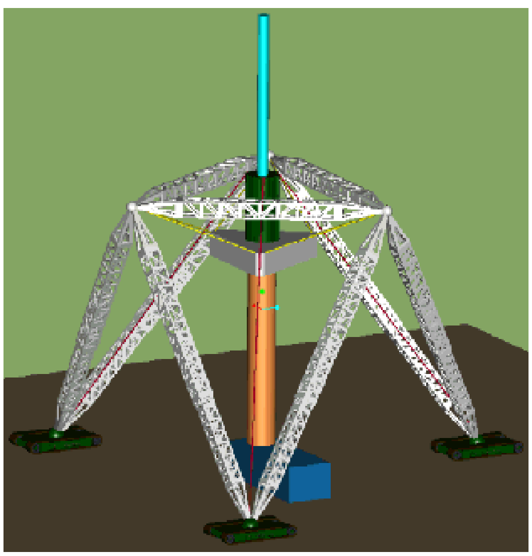

Figure 11

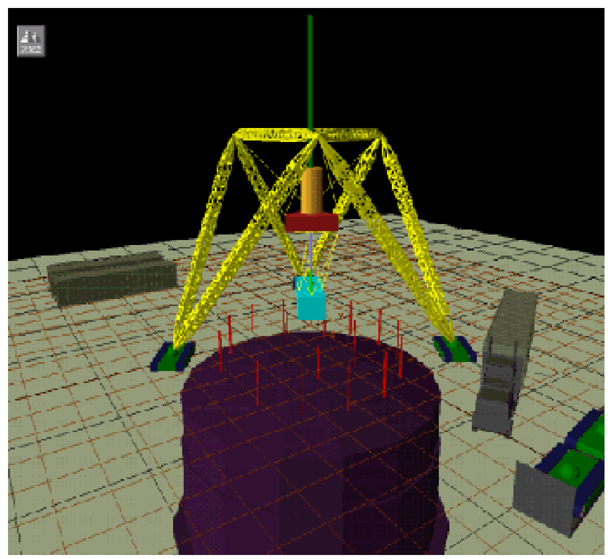

Figure 12

Figures 11. RoboCrane®/EMMA 3D Solid Model developed using Pro/Engineer
Figure 12. TGRIP Simulation Snapshot of the RoboCrane®/EMMA Waste Storage Tank Remediation Concept. The RoboCrane® is approaching the waste storage tank prior to deployment of the EMMA into the tank to clean it.

Summary and Conclusions

The RoboCrane® applications illustrated in this overview provide an excellent example of simulation and modeling applications for advanced systems. This saves expenses in constructing prototypes. Critical design information can be learned in the following areas: mechanical design and assembly, task planning, control system requirements, and operator interface development. As our design capabilities improve and interactions with other design development methods continue, the results will be reduced cost and more efficient systems. We are researching advanced RoboCrane® concepts while researching CAD and simulation tools available today.

ISD has a goal to develop and implement Intelligent Systems Architecture for Manufacturing (ISAM). [10] In advanced systems like RoboCrane®, software tools will be important in the operator interface development and will relate to all the levels of the ISAM hierarchical structure. All simulations developed in RoboCrane® applications have the potential of becoming part of this operator interface and help us better understand how to interact with the intelligent systems. TGRIP and other tools give ISD the capabilities to excel in designing robust systems. Through application of these design tools, we are learning more about what an intelligent system is, how we should communicate with it, and how we can efficiently develop it.

Acknowledgements

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Video Summary

The corresponding short video developed for this report includes: MOB RoboCrane® Bridge Construction RoboCrane®, and RoboCrane®/EMMA simulations. To receive a copy, contact:

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