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ROBOCRANE AND EMMA APPLIED TO WASTE STORAGE TANK REMEDIATION

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Abstract

The RoboCrane is a revolutionary concept in crane automation. The RoboCrane, based on the Stewart platform parallel link manipulator design, consists of cables as the parallel links and winches as the actuators. The result is a work platform that can maneuver tools and/or manipulators with full six degree-of-freedom control. EMMA, a serpentine manipulator, is currently being developed for several applications, including the delivery and orientation of end-effectors throughout nuclear waste storage tanks. The combination of Robo- Crane and EMMA can provide an adaptable and highly effective means for waste storage tank remediation.

Keywords: RoboCrane, EMMA, parallel link manipulator, Stewart platform devices, cable-based robots, cranes.

1.0 RoboCrane

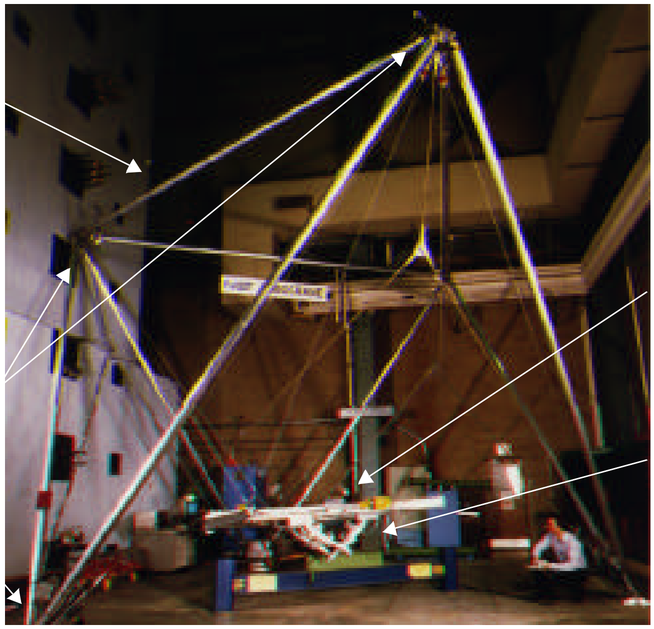
Since the late 1980's, the National Institute of Standards and Technology (NIST) has been working on the RoboCrane®. The RoboCrane is a cable driven, multi-purpose manipulator based on the Stewart platform parallel link manipulator [1]. It provides full six degree-of-freedom (6 DoF) load control via tele-operative, semi-autonomous and autonomous control modes. Originally, the RoboCrane was developed under a Defense Advanced Research Project Agency (DARPA) contract to stabilize crane loads [2]. Currently, the configuration has advanced to include air-lifted, land, sea, 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 (ISD) provides "... research in, develops methods for, and applies intelligent systems technology to improve U.S. industry competitiveness." The RoboCrane provides an intelligent machine enhancement to current large scale manufacturing methods. It also provides a means for manipulating tools and equipment, such as long-range manipulators and end-effectors, into waste storage tanks for inspection and remediation.

Multiple RoboCrane prototypes have been developed to study a variety of applications. A 6 m octahedral system (see FIGURE 1) has performed heavy load maneuverability, sawing, grinding, gripping, welding, and assembly tasks under tele-operative, preprogrammed, off-line, and/or hybrid control modes.

The 6 m RoboCrane prototype has been subjected to a variety of performance measurements and computer simulations [3]. Experimental tests were conducted to verify its functional work volume, static loading capability, and load positioning accuracy. These experimental results compared favorably to associated computer analysis. Positioning uncertainty of this 6 m prototype has been measured at up to 1 mm in translation and angular precision of approximately 0.5° throughout a minimum 100 m^3 work volume while using teleopera-

FIGURE 1. Six Meter NIST RoboCrane Prototype.

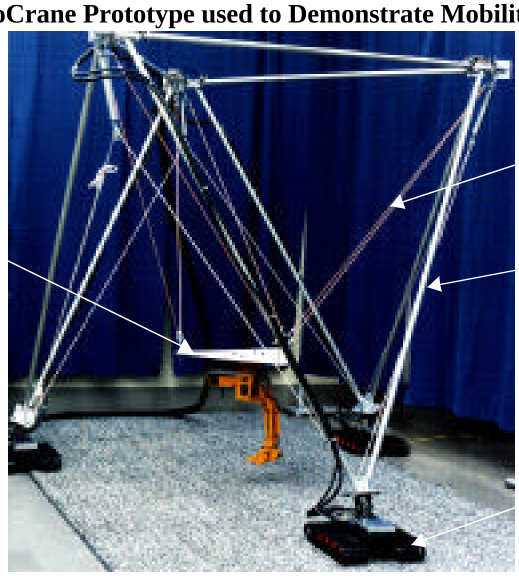


tion.

The RoboCrane work platform has been equipped with tools such as a gripper, grinder, welder, saw, and inspection equipment (stereo vision and laser scanner). These tools have been used to demonstrate a variety of tasks. Each new application has contributed to the overall functionality of the RoboCrane controller and to the design of the human/computer interface. The current controller implementation provides for intuitive and robust control of the RoboCrane through the following control modes: master/slave; joystick input; operator panel input; preprogrammed trajectory following (teach programing, graphical off-line programing, or part programing); and sensor based motion compensation. Individual winch control is also possible. [4]

The RoboCrane's structure is well suited for mobility. By affixing independent wheeled vehicles under each of the structure's three feet, the RoboCrane can be made to traverse rough terrain. This was demonstrated using a 2 m, radio controlled prototype as shown in FIGURE 2.

FIGURE 2. Two Meter RoboCrane Prototype used to Demonstrate Mobility.



The RoboCrane's octahedron structure can be made extremely lightweight compared to conventional gantry structures.

2.0 EMMA

Recently, the Intelligent Systems Division began a Cooperative Research and Development Agreement with Grey Pilgrim, LLC. to study the concept of a RoboCrane deploying a serpentine style manipulator, called EMMA (Easily Manipulated Mechanical Armatures) [5], into a waste storage tank for inspection and remediation of high-level radioactive waste (see FIGURES 3 and 4). A 27 m tall by 23 m diameter RoboCrane can deploy a 21 m long EMMA (including a 15 m long, 3 stage arm attached to a 6 m straight shaft) into the tank from any tank riser location so that little or no tank modification is necessary. EMMA can be shrouded as shown in the figure. An EMMA prototype (3 m long) has been integrated onto the 6 m RoboCrane (see FIGURE 5) for study and experimentation. EMMA is composed of hollow cylindrical stages of user-selectable length, diameter, and flexibility, and can be built for specific tasks. The prototype shown in FIGURE 5 is currently being used to verify fundamental design and control issues. Scale-up for a 12 m version is now being designed.

The development phase for EMMA has been marked by a substantial amount of testing and analysis in the following areas: kinematics and control, static and dynamic load-bearing, obstacle avoidance, and waste handling.

3.0 RoboCrane and EMMA Applied to Waste Storage Tank Remediation

When combining the RoboCrane and EMMA (see FIGURES 3 and 5)[6],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

FIGURE 3. Concept of the RoboCrane and EMMA Applied to Waste Storage Tank Remediation: a) EMMA ready for deployment into the tank, b) EMMA deployed into the tank.

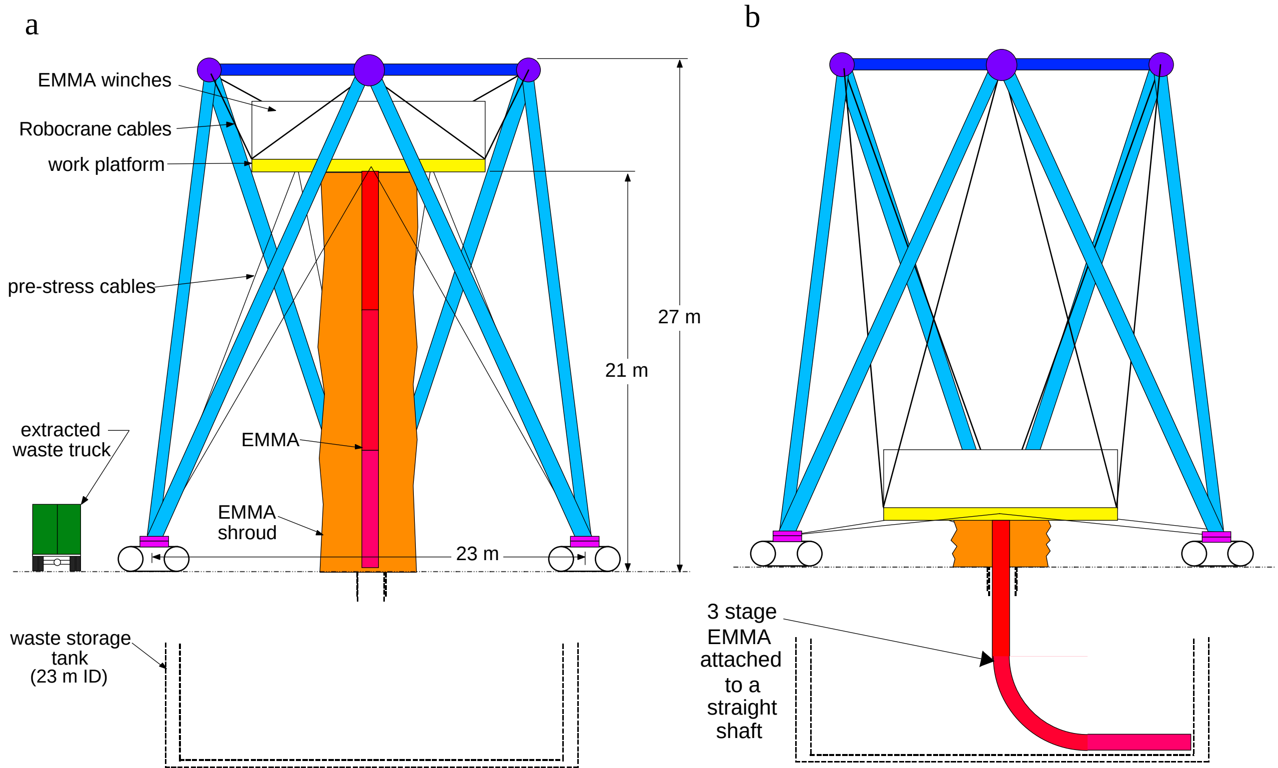
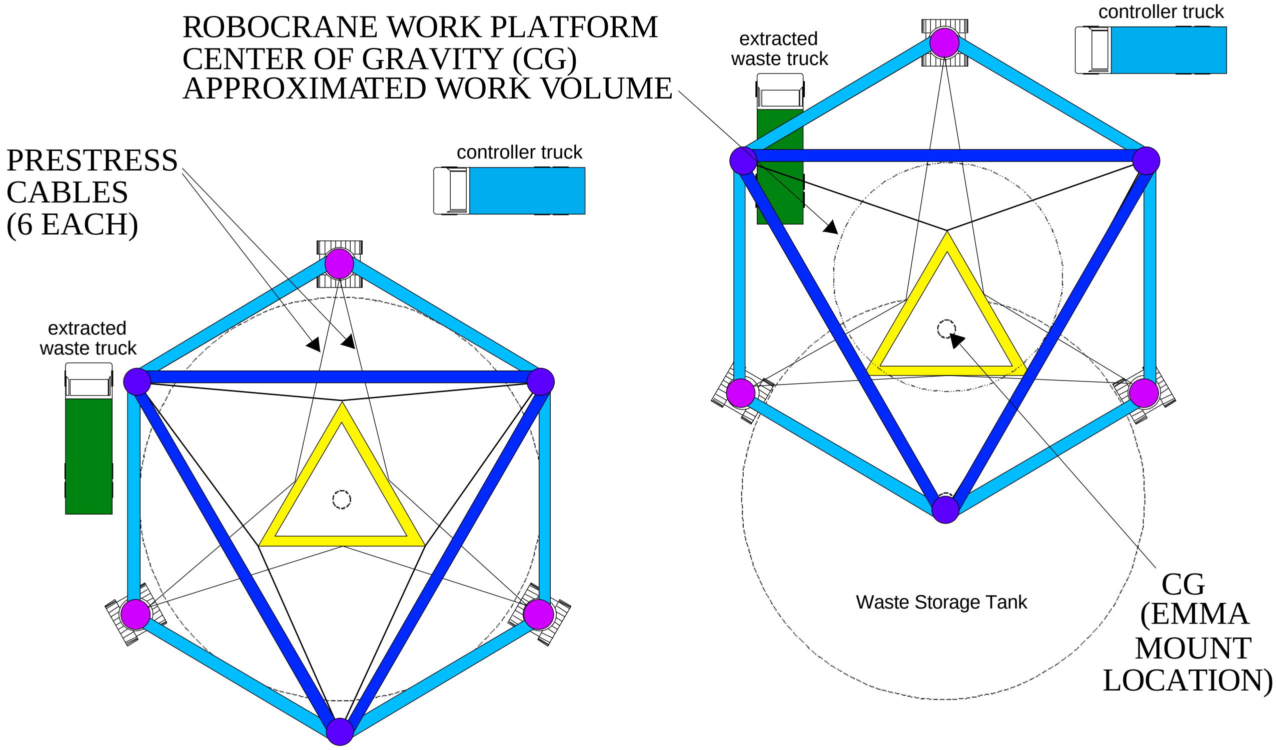


FIGURE 4. Top Views of the RoboCrane Straddling a Waste Storage Tank Reaching all Risers



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.

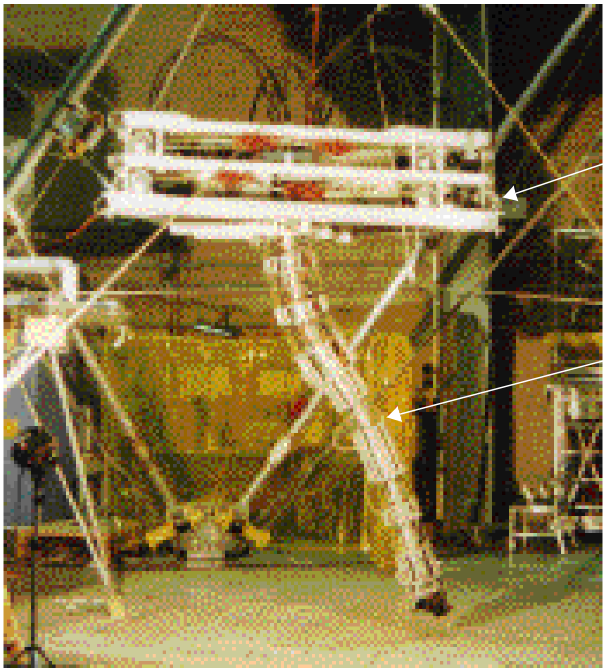
Pre-stress cables, as shown in FIGURES 3 and 4, are planned to preload the work platform and compensate for work platform "soft constraint" conditions. This softness becomes a problem when the RoboCrane cables form small angles with the vertical. To assure that soft constraint conditions are minimal, prestress cables can apply horizontal forces to the work platform to constrain it throughout the entire RoboCrane work volume during EMMA placement into the tank or during retrieval operations.

A non-contact sensor ring placed at the tank riser opening and/or capacitive type sensing along the arm can be used by the controller to assure that the arm does not contact the tank riser. Once the arm is lowered into the tank, the RoboCrane work platform serves as a stable base from which EMMA can perform waste tank remediation. Waterjet or other tools will be used to extract and retrieve the waste. The waste is pumped into a waste truck or above ground holding tank.

Work is currently underway to allow EMMA to "feel" around the tank using non-contact sensing. Teleoperative control is currently available for the EMMA and soon will incorporate sensor feedback to navigate around for in-tank hardware.

Mobility also allows the RoboCrane to be constructed outside the tank area where cranes and workers can readily and efficiently construct the Robocrane and EMMA. Once constructed, the RoboCrane and EMMA can drive over the target tank and begin remediation processes. The RoboCrane gantry is designed to place no pressure on the tank. Hinged joints in the gantry allow the RoboCrane to be mobile over uneven terrain. RoboCrane mobility can provide EMMA movement from tank to tank (see FIGURE 4).

FIGURE 5. EMMA Prototype suspended from the 6 m RoboCrane Prototype.



4.0 Summary and Conclusions

The RoboCrane has been developed, and critical characteristics and control issues have been studied. Similarly, the EMMA has been designed, a prototype has been built, and ongoing analysis and controller efforts are proceeding.

The RoboCrane prototype is based on the Stewart platform parallel-link manipulator. It uses cables as the parallel links and winches as the actuators. It can control the position, velocity, and force of tools and heavy machinery in all six degrees of freedom (x, y, z, roll, pitch, and yaw).

The current RoboCrane control system allows full remote control of RoboCrane functionality.

Further RoboCrane controller development is envisioned for force control and automatic functions, and will soon be implemented on the EMMA, as well.

A RoboCrane and EMMA combination has been proposed for waste storage tank remediation. Prototypes of both systems and their integration have been developed. Further development of the RoboCrane and EMMA is envisioned and will provide knowledge and experience necessary for full-scale systems design.

5.0 References

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