A TOOL TO IMPROVE EFFICIENCY IN LARGE SCALE MANUFACTURING

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ABSTRACT: NIST is working directly with industry to improve repair and conversion operations of ships in dry dock. This work allows transfer of technology to construction and other industries requiring worker-access to large, external surfaces with minimum footprint and maximum system rigidity and control, while augmenting conventional suspended-scaffold systems and moving toward more autonomous large-scale manufacturing applications such as building construction.

KEYWORDS: worker access, ship repair, construction, robotics, cable controlled, large-scale manufacturing

INTRODUCTION

The Manufacturing Engineering Laboratory of the National Institute of Standards and Technology (NIST) has teamed with Atlantic Marine, Inc. in Mobile, Alabama to study efficient methods to repair ships in dry dock or along a pier. This project, called Knowledge-based Modular Repair [1, 2] is under the auspices of the Navy National Shipbuilding Research Program Advanced Shipbuilding Enterprise Initiative, where worker-, equipment-, and material access to external ship surfaces was determined to be a key focus area. The concept developed in this project is called the "Flying Carpet" and combines two main technologies: the NIST RoboCrane [3] and commercially available suspended scaffolding to produce an effective concept for worker access to ships, submarines, buildings, and other large objects.

The NIST Intelligent Systems Division developed the RoboCrane cable-controlled manipulator over several years [3, 4, 5, 6], during a project for the Defense Advanced Research Project Agency (DARPA) that studied crane suspended load control. Since the DARPA project, NIST has expanded RoboCrane technology into a viable solution to address large-scale manufacturing and many other challenges [7]. The RoboCrane applies the Stewart-platform parallel-link manipulator technology to a reconfigurable, cable-driven system. While RoboCrane can lift large, heavy

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and awkward loads, its stability and maneuverability allow advanced programming techniques more analogous to robots than cranes. The RoboCrane combines sensors, computers, and lightweight tensioned cable machines for performing heavy manufacturing and construction tasks. These tasks can include lifting and positioning heavy loads; manipulation of workers, tools and parts for improved worker accessibility and assembly; and fixturing, welding, cutting, grinding, machining, surface finishing and inspection.

Recent research has yielded the Flying Carpet concept as a movable scaffolding and worker positioning system that enables workers to maneuver themselves, parts, and tools throughout a large work volume for tasks such as ship repair and aircraft paint removal with up to 20-times improved efficiency over hand-built scaffolding. The Flying Carpet is a cable-supported platform that uses single-axis jog-, velocity- and force-control modes. A photograph of the 1:120 scale concept model is shown in Figure 1.

Figure 1. NIST Flying Carpet 1:120 scale concept model showing the ship bow/stern access configuration (right) and the ship side access configuration (left).

Beyond this step is envisioned a combined closed-loop system, whereby the Flying Carpet can autonomously and rapidly lift, position, and fixture heavy, bulky steel plates onto ships in dry dock during repair and conversion operations. Similarly, the system can be used for more autonomous assembly applications on construction sites. This paper will detail the Flying Carpet concept, status, and provide a look to the future toward the construction of buildings and more autonomous manufacturing.

CONCEPT

Small and full scale static physical models, a computer model for studying system work volume, and a full-scale working prototype were built to demonstrate the advanced functionality of the Flying Carpet as a tool for ship repair and other uses. Figure 2 shows a photograph of the full-scale working prototype Flying Carpet configured for ship bow/stern access. Its basic geometry includes four upper support points, instead of three, to match the dry dock configuration. These are connected to three work-platform points with six cables.

The four upper support points can be attached to towers mounted to a dry dock, on the ground, along a pier, to a gantry, or to the ceiling, walls, or other superstructures. Two front cable pairs provide platform lift while two rear cables mount lower to pull back on the platform, creating a rigid system. Cables can be multi-part lines for added safety and lift capacity. By suspending the platform from above, the RoboCrane improves operating efficiency by “flying” over ground-clutter or landscaping that typically hinders wheeled vehicles at the work site.

Hoists that control each cable’s length can be mounted on the support structure or the work platform. The total hoist rigging capacity of the prototype, which uses two-part wire ropes, totals 8200 kg. In the prototyped configuration, the Flying Carpet carries its hoist motors, which provide a stabilizing counterweight. Motor location on the platform also eliminates the problem of mounting motors on the surrounding support structure, making the platform easier to reconfigure.

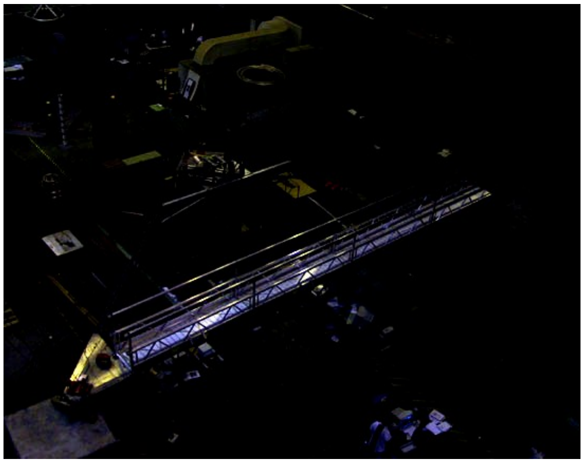

Figure 2. Full-scale Flying Carpet prototype top view shown in the ship bow/stern access configuration.

Welders, paint sprayers, or other equipment can be mounted to the Flying Carpet. The platform allows rapid fixturing of tools, equipment, or cargo to provide direct worker access to the equipment as needed at the site. The Flying Carpet cable configuration provides a constrained and easily maneuvered work platform as compared to conventional worker-access systems typically used for ship repair, thereby aiding ship welding and inspection tasks.

The platform provides minimized sway and rotation, and can exert forces and torques with full six degree-of-freedom control. Flying Carpet motion types include Cartesian and joint modes. Cartesian control allows the worker to very simply move the platform front-to-back, side-to-side, and up-and-down, as well as yaw about the vertical axis, all while maintaining level. Joint mode allows single-hoist motion for setup or cable replacement for normal maintenance.

Platform levelness is ensured by both the platform kinematic control and through a redundant level sensor. Operator control is through the tethered joystick, either worn by the operator or mounted to the platform. With the platform, an on-board or remotely-located operator can manipulate and hold attached materials, such as heavy steel plates, or tools, such as welders, grinders, robots and other cargo only dependent upon the platform rated capacity. Tension sensors in-line with each cable prevent hoist or platform overloading from occurring. An on-board supply hoist can also be attached to the platform to bring tools, workers, and supplies up to the work site while the platform is parked in position.

The full-scale prototype configured for ship bow and stern access measures 14.5 m wide x 7 m deep x 2 m high. Six hoists, each rated to lift 680 kg, can carry 680 kg of workers, materials, and equipment in addition to the 1400 kg weight of the platform itself, with at least a 5 times safety factor.

Performance measurements and cable configurations were tested on the full-scale testbed prior to planned testing in a shipyard dry dock. Constrained by the NIST facility spacing of 18 m simulated tower height x 21 m width x 14 m depth for front-to-back attachment point distance, the full-scale Flying Carpet prototype demonstrated: 10 m lift, 9 m forward-to-back motion, 5.5 m side-to-side motion, and yaw of more than ± 25° before the cables went slack. The translational work volume should scale well to the larger dry dock environment.

PLATFORM RECONFIGURATION

The Flying Carpet can be reconfigured from ship bow and stern access to a thin, ship side-access configuration as shown in Figure 3.

Reconfiguration from the bow and stern access to the side access configuration includes: removing the hoist platform (computer, power, and attached cables); removing the rear truss assembly; moving the hoists and pulleys to match the new configuration; re-spooling the cables; and pushing a button on the joystick to tell the computer that the configuration has changed. In this configuration, the 23 m depth is reduced to 2 m, allowing it to fit between the dry dock wing wall and the ship side.

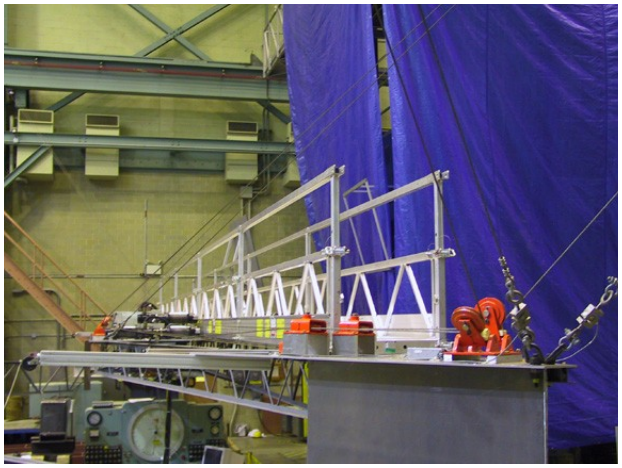

Figure 3. Full-scale Flying Carpet prototype top view shown in the ship side access configuration. The full-scale platform is near a mock ship (photo right) and in this test there was no dry dock wing wall to push against with the platform outriggers.

It took a team of 3 workers 13 man-hours to perform platform reconfiguration over about 4 clock hours. It is estimated that this time could be reduced to 3 to 6 man-hours (or 1 to 2 clock hours) with further experience. If a second platform were used for ship side-access along with a ship bow and stern access platform, this reconfiguration time would not be necessary.

The demonstrated work volume in the side access configuration with support points spaced at approximately 8 m x 21 m x 8.5 m high allows 6 m platform motion forward-and-back, 5.5 m side-to-side, and moves 6 m high. Yaw motion is limited to approximately 5° due to the reduced front-back depth and reduced rear platform depth. The platform in this configuration includes similar rigidity characteristics as in the bow and stern access configuration.

For platform heights above the dry dock wing wall, the cables are at smaller angles with the horizontal axis and therefore provide the lateral stiffness necessary for upper ship side-access, at a cost of increased cable tension. Vertical stiffness is reduced. In this case, all cables are mounted at the same height, where two cables attach to one of two towers as shown in the model in Figure 4.

Figure 4. Photograph of the Flying Carpet 1:12 scale model shown in the ship side access configuration. The 1:12 scale model shows a tower attached to the dry dock wing wall and the platform pushing against the wall.

Two front cables can instead be crossed for even more rigidity, and towers (support points) can be separated by 30 m or more providing a very large range of motion side-to-side. Along the wing wall, similar platform rigidity can be accomplished by pushing against the dry dock wall with outriggers that could be adjusted manually or automatically.

APPLICATION TO THE CONSTRUCTION INDUSTRY

The concept of a Flying Carpet can also be applied to the construction industry. Figures 5 and 6 show a graphic of this concept and photographs of a scale model, respectively. For quick or prolonged and non-intrusive access to external building surfaces, the Flying Carpet can be attached to inflatable columns or other superstructures (e.g., building corners, aluminum or steel columns) and maneuvered about the building surface. Columns instead of building corners allow the Flying Carpet to be attached to unfinished structures. The columns can be made of a lightweight material, such as sailcloth, light enough for a single worker to set up from the ground. For example, a column 1 m in diameter, inflated to 70 kPa (10 psi), can support more than 5000 kg of weight. Given the stiffness of sailcloth, 1-m diameter columns up to 25 m long should have no tendency to buckle. Longer columns should be larger in diameter to preclude buckling. A small air pump could be used to fill the structure and lift the support points high above the building structure. Guy wires could be used to stabilize the structure. With this concept, a worker could theoretically reach all external building surface points for performing window or wall section insertion, window washing, brick laying, cleaning, or many other tasks associated with building construction or maintenance.

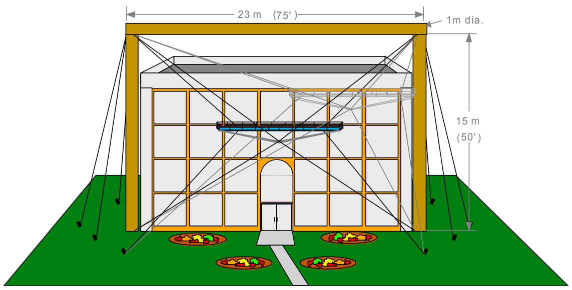

Figure 5. Graphic of a model Flying Carpet applied to external building surface access.

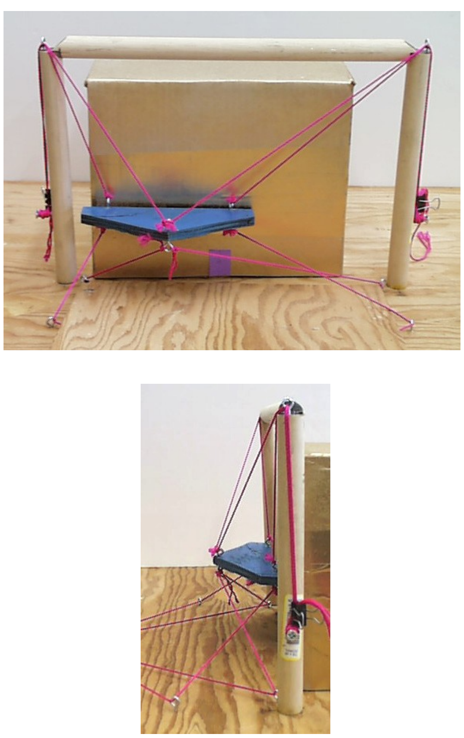

Figure 6. Model Flying Carpet front (top) and edge (bottom) applied to external building surface access. The wooden supports simulate inflatable columns or other superstructure that supports the Flying Carpet.

FUTURE CONCEPTS

One of the next steps in the Flying Carpet development effort is to provide navigation capability for platform operation in semi- or fully-autonomous modes. Although relative platform movement can be derived from winch encoders, encoders alone cannot reveal changes in platform position due to load variation or sway, nor will they easily map to the complex shape of a ship or submarine hull. A position reference system (absolute or relative) is desired to enable flight path trajectory planning for the Flying Carpet.

The Construction Metrology and Automation Group at NIST is currently instrumenting a RoboCrane platform with a three-dimensional, laser-based site measurement system (SMS) for absolute position control in all six degrees-of-freedom. [8] The project, part of the Automated Steel Construction Testbed, will be used to demonstrate autonomous steel pick and place operations. Follow-on experiments will incorporate registered LADAR (laser detection and ranging) scans of the work site for task analysis and navigation planning.

A similar navigation package will be employed for the Flying Carpet using the registered LADAR scans to map the hull as a boundary surface. The SMS will then be used to track the Flying Carpet along that surface. An advantage of this method is that the LADAR data from the scan also provides detailed 3D information that can be used to map damaged areas, create cutting/rolling templates for repair material, analyze surface imperfections, and generate as-built data for pre- and post-repair.

SUMMARY AND CONCLUSION

The Flying Carpet is a reconfigurable cable-controlled platform based on the Stewart Platform parallel mechanism. The Flying Carpet provides the dexterity, precision, and large work-volume needed for dry dock and/or pier side ship repair, as well as for other large-scale manufacturing applications. The Flying Carpet can be reconfigured and can attach to towers or existing superstructures to eliminate unnecessary equipment costs. Tools and equipment can be attached to the Flying Carpet quickly and easily for many worker-assisted tasks. The Flying Carpet operator can be located at the work site or at a remote location to provide safe and efficient worker placement. The Flying Carpet is a demonstrated technology, ready for commercialization. Advanced concepts toward autonomous construction are also being considered.

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