The Flying Carpet

Engineers from the US National Institute of Standards & Technology have designed a way of using hoists and ropes to access awkward spots

Floating on a web of wire rope, the Flying Carpet can reach remote corners of large cargo or passenger ships under construction in dry dock. It is quicker to set up than normal scaffolding and relatively inexpensive – parts cost about $60,000, vastly cheaper than a large gantry crane. Like a crane, it uses hoists for lift, but the resemblance ends there.

Electric overhead travelling cranes need a gantry system to move a hoisted load horizontally. Hoists only work on one axis – they pull toward their rope drum, or drop a load away from it. Winches, which pull a load from one side, still only operate in one dimension.

But the Flying Carpet, like its progenitor, a 1980s design called the RoboCrane, moves not in one but six directions. The RoboCrane was a kind of adaptation of another idea from the world of robotics, the Stewart Platform parallel-link manipulator.

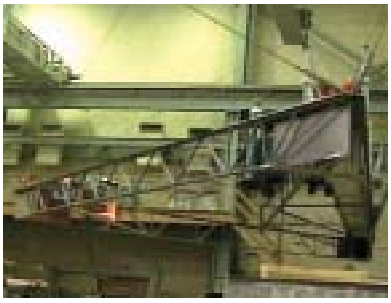
Six rods control every movement of a sheet of metal in the centre. Push one, and the metal tilts or moves in one direction. The Platform has a total of 12 movements – both directions along the x, y, and z (vertical) axes, and around them in pitch, roll and yaw.

For the Stewart Platform's rods, the RoboCrane substituted wire rope. Where the Stewart Platform is moved by rods that push, the RoboCrane's platform is moved in a direction by winches pulling on the rope. The Flying Carpet design uses six hoists and a computer to move a work platform in three dimensions.

"By attaching the cables to a work platform and keeping all cables in tension, the load is kinematically constrained, and the work platform resists perturbing forces and moments with equal stiffness to both positive and negative loads," according to a 1994 paper written by the developers*. "The result is that the suspended load is constrained with a mechanical stiffness determined by the elasticity of the cables, the suspended weight, and the geometry of the mechanism."

The designers have built a full-scale working prototype in a test facility. They intend to transfer this technology to other industries and/or government, to study construction applications and to study autonomous navigation of the Flying Carpet. They envisage 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. Or it could be used for more autonomous assembly applications on construction sites.

The Construction Metrology & Automation Group at NIST is instrumenting a RoboCrane platform with a three-dimensional, laser-based site measurement system (SMS) for absolute position control in all six degrees-of-freedom. Follow-on experiments will incorporate registered LADAR (laser detection and ranging) scans of the work site for task analysis and navigation planning.



The full-size Flying Carpet prototype equipped with welding gear

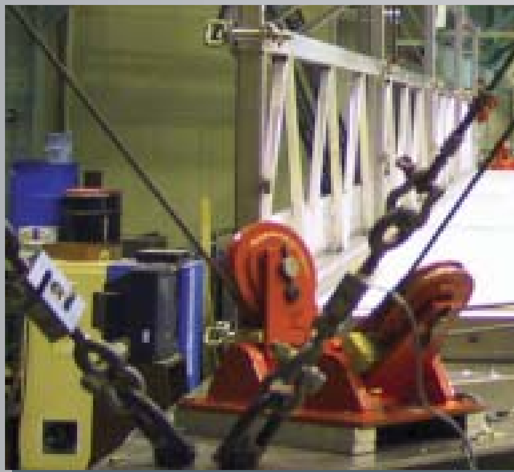
Bostelman, R., et al. 'Applications of the NIST RoboCrane,' Proceedings of the 5th International Symposium on Robotics and Manufacturing, Maui, HI, 14-18 August 1994

The Project

The Manufacturing Engineering Laboratory of the National Institute of Standards and Technology (NIST) teamed with Atlantic Marine, Inc. in Mobile, Alabama to study efficient methods to repair ships in dry dock or along a pier. The concept developed in this project, called the Flying Carpet, combines two main technologies: the NIST RoboCrane and commercially available suspended scaffolding to produce an effective concept for worker access to ships, submarines, buildings, and other large objects.

While RoboCrane can lift large, heavy and awkward loads, its stability and maneuverability allow advanced programming techniques more analogous to robots than cranes. The RoboCrane combines sensors, a computer, a platform and tensioned cables to perform heavy manufacturing and construction tasks, such as: lifting and positioning heavy loads and manipulation of workers, tools and parts. The RoboCrane manipulator can improve worker accessibility to ships and buildings for performing tasks such as: assembly, 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 expected 20-times improved efficiency. This efficiency is based on a comparison of scaffold set-up time observed at the shipyard (at least 64 man-hours) versus expected Flying Carpet deployment time extrapolated from NIST RoboCrane experiments (3 man-hours). The Flying Carpet is a cable-supported platform that uses single-axis jog-, velocity- and force-control modes.



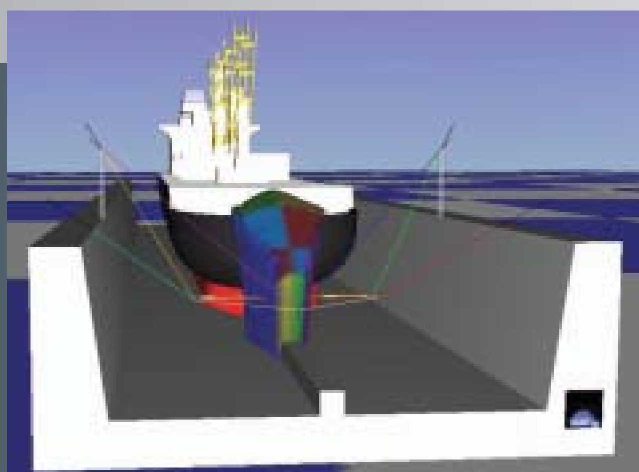
Two cables terminate at each corner of the Flying Carpet. Cable runs start at the hoist's rope drum, then travel through pulleys located near the anchor point, loop around a snatch block, and then fastens to the Flying Carpet through an S-shaped load cell

Operator uses a joystick to manoeuvre the Flying Carpet. The joystick mimics some of its movements: push the joystick forward and back and side to side to move along the Y and X axes. Twist the joystick to move up and down (marked Z). The odd one out: yaw. To pivot along the vertical axis, operators press and hold a thumb button (not visible) and twist. The control also includes a red emergency stop button and a hoist set-up dial

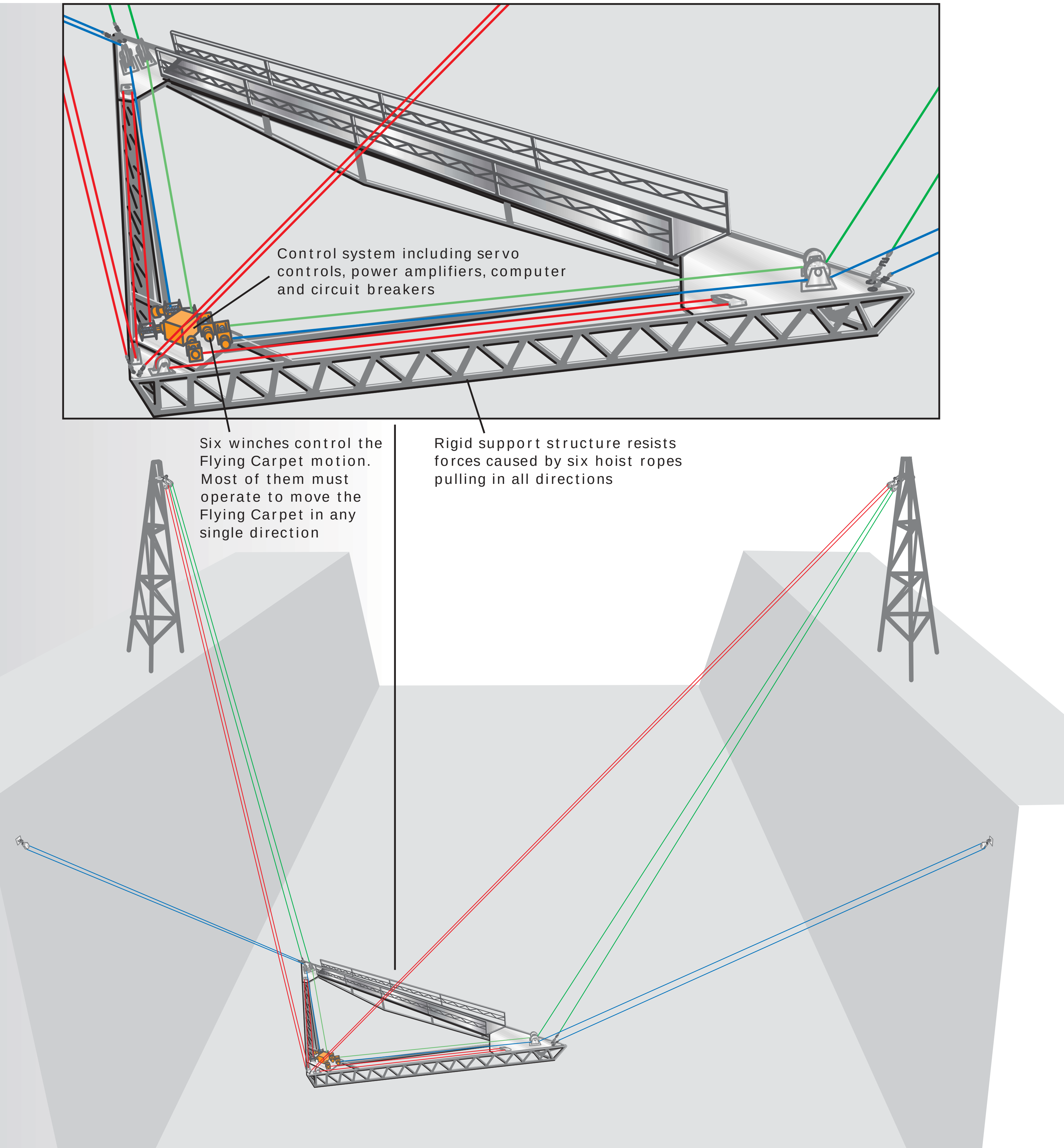
Specifications

Overall system dimensions: 31m (100ft) wide by 12m (40ft) deep
Work platform dimensions: 18m (60ft) wide by maximum 6m (20 ft) deep
Wire rope cable length: 46m (150ft)
Maximum yaw rotation: +/- 25°
Working height: up to 24m (80ft)
Platform weight: 2.5t (2.8 US tons)
Estimated total cost to build: $60,000, including $40,000 on winches and pulleys, $11,200 on structure and $7,800 on electronics in 2003 prices
Suggested winch: 2.2kW three-phase Jeamar NLT 2800, fourth layer (minimum) working load limit rope pull of 972kg with 10mm wire rope

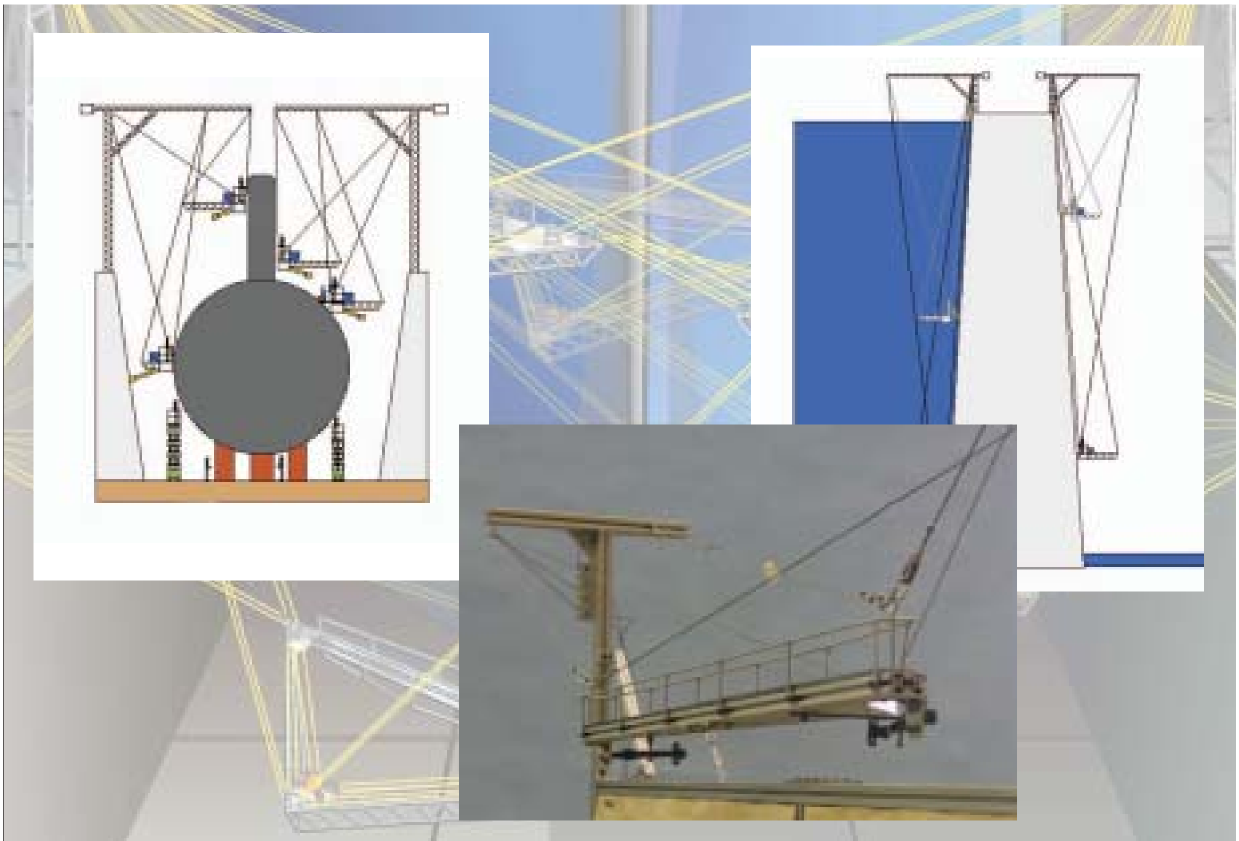
Figures apply to a full-size Flying Carpet installed at the facilities of collaborator Atlantic Marine.
The NIST does not endorse products; winch model chosen only for purpose of price estimate



A computer simulation of the Flying Carpet's range of motion, rendered in a 3D object. The picture plots the maximum extent of the platform's centre of gravity, rendered into a 3D object. (That means that the ends of the platform can actually reach much farther to either side). Because it can move backward as well as side to side, the Carpet can track the bow from top to bottom



An extra dimension on a suspended work platform:
Six computer-controlled winches enable the Flying Carpet to move in the direction of, and around, all three axes. On each side, a set of three cables (each in different colours) hold the Flying Carpet stable



Because the Flying Carpet can move in three dimensions, it can manoeuvre around any complex object, such as a submarine (near right) or a dam in operation (right)

The Flying Carpet can be rigged differently for navigating flat surfaces, such as buildings or the sides of ships.
Right: a scale model of the Flying Carpet in the ship side-access configuration

The Concept

Small and full scale static physical models, a computer model for studying system work volume and a full-scale working prototype demonstrate the advanced functionality of the Flying Carpet as a tool for ship repair and other uses. Its basic geometry includes four upper support points, instead of three as used for RoboCrane, to match the rectangular dry dock configuration. The four points connect to three work-platform points with six cables in a unique configuration creating a relatively rigid system.

The four upper support points can be attached to towers mounted to a dry dock, ground, or along a pier, to a gantry, 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 factor 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 mount on the support structure or the work platform. The total hoist rigging capacity of the prototype, which uses two-part wire ropes, totals 8,200kg (18,000 lb). In the prototyped configuration, the Flying Carpet carries its hoist motors, providing maximum platform flexibility as well as providing a counterweight.

Welders, paint sprayers, or other equipment can mount 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.

An on-board supply hoist can also attach to the platform to bring tools, workers, and supplies up to the work site while the platform is parked in position. 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 repair and inspection tasks.

The platform provides minimized sway and rotation, and can exert forces and torques with full six degree-of-freedom control. The operator commands 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 dependent upon the platform rated capacity. Tension sensors in-line with each cable can prevent hoist or platform overloading or sense slack cables.

The Flying Carpet moves in Cartesian and joint modes. Cartesian control allows the worker to intuitively move the platform front-to-back, side-to-side, up-and-down, and yaw about the vertical axis all while maintaining platform level. Joint mode allows single-hoist motion for setup or cable replacement for normal maintenance.

The Flying Carpet can be reconfigured from ship bow and stern access as discussed above to a thin, ship side-access configuration as shown in Figure 3. 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 and some reduced vertical stiffness. Two front cables can be crossed for additional rigidity and the towers (support points) can be separated by 30m or more to provide a large, side-to-side range of motion. Along the wing wall, similar platform rigidity can be accomplished by pushing against the dry dock wall with outriggers.

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Adapted from:

Bostelman, R., Shackleford, W., Proctor, F., Albus, J., Lytle A., 'The Flying Carpet: A Tool to Improve Ship Repair Efficiency,' Proceedings of the American Society of Naval Engineers Symposium on Manufacturing Technology for Ship Construction and Repair, Bremerton, WA, 10-12 September 2002.
Further information from:
www.isd.mel.nist.gov/projects/robocrane