STABILITY OF AN UNDERWATER WORK PLATFORM SUSPENDED FROM AN UNSTABLE REFERENCE

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***Abstract* - A work platform suspended by six cables and controlled by six winches located on a vessel, can precisely control the position, velocity, and force of tools, grippers, and machinery in all six degrees of freedom (x, y, z, roll, pitch, and yaw) while the vessel is moving due to sea surface conditions. Based on the Robocrane, the platform can be maneuvered via operator controls (eg. a joystick) for doing work without disturbance of the sea bottom by controlling the cable tensions and buoyancy of the work platform. Large forces and torques can be exerted with the work platform while being controlled from a remote position. Many applications are possible: from underwater pipe-laying/repair to construction, in other than mild weather conditions.**

1. INTRODUCTION

A new crane design utilizing six cables to suspend a load platform was first developed by the National Institute of Standards and Technology (NIST) in the early 1980's. A NIST program on robot crane technology, sponsored by Advanced Research Projects Agency (ARPA), produced the design, development and testing of three different sized prototypes to determine the performance characteristics of this proposed robot crane design. A description of the overall DARPA program and the results of this research are presented in [1]. Initial testing of these prototypes showed that this design results in a stiff load platform [2, 3]. This platform (see figure 1) can be used in typical crane operations, or as a robot base, or a combination of both. Applications of this new crane design in the construction industry are illustrated in [4]. As part of the research being done on the Robocrane, the authors have applied this unique system design to an underwater type Robocrane that uses a floating vessel as the support structure for the work platform. This causes an interesting concept where the upper support platform is no longer a stable reference for the lower platform, but is an unstable reference that still allows for a stable work platform. This new concept is called,the "Submerged, Stabilized, and Suspended Platform (S3P)."

The objective of this paper is to briefly describe the S3P, its functional capabilities, and its conceptual design. The primary function of the S3P is to lift, maneuver, and position large loads with precise control of position and force in all six degrees of freedom while suspended from a floating vessel susceptible to water and air currents. The S3P has the following potential functional capabilities: cutting, lifting and positioning, flexible fixturing, welding, and grinding. To date, the S3P is a concept ready for system design and fabrication. A number of advantages of the S3P over current technology are: rigid support and precise maneuverability of large loads, remote positioning of tools, equipment and materials, executing precise motions with tools/equipment to accomplish complex tasks, resistance to environmental perturbations, accurate control of loads by a novice operator, and reduced crew size. Depending on the application, the S3P operator could control the work platform from either the floating vessel or directly from the work site.

The next sections describe the conceptual S3P system design, the S3P control, and followed by a section stating some advantages and differences from existing technology. A summary and conclusion section follows, as well as a list of references for the paper.

2. SYSTEM ARCHITECTURE

The S3P system design evolved from previous Stewart Platform work using cables from winches as the parallel links and actuation instead of linear actuators as used in the past. When all six cables are in tension, the platform is kinematically constrained, and there exists a known mathematical relationship between the lengths of the six cables and the position and orientation of the platform. The theory of this mathematical relationship has been known for many years and was first embodied in a Stewart Platform for testing tires in the 1950's [5], and applied to aircraft flight simulators during the 1960's and '70's. It was applied to cable driven manipulators by Landsberger [6,7] and to cranes by NIST in the 1980's [1].

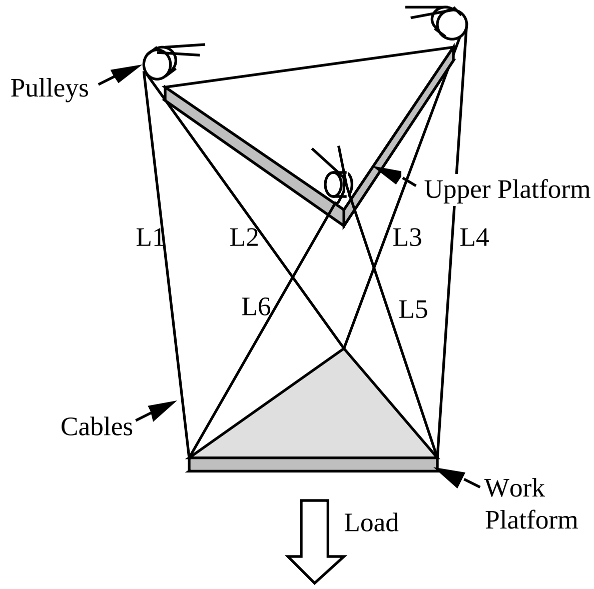

Figure 1 - Basic Concept of Stewart Platform Parallel Link Manipulator using cables as parallel links.

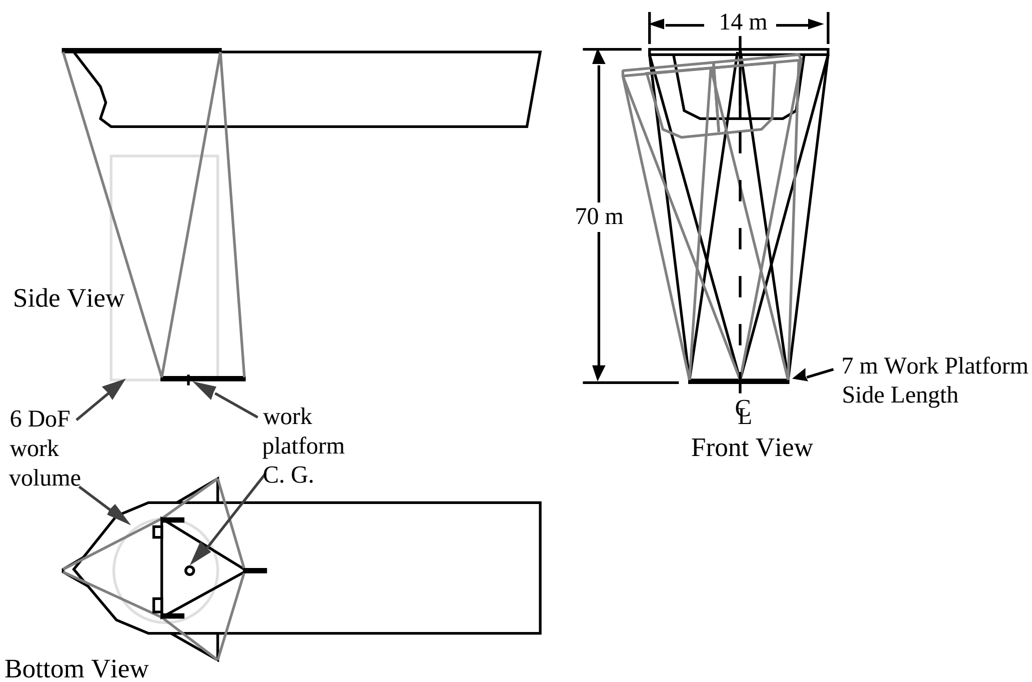

Figure 2 - Multiple views of the S3P suspended from a vessel. Front view shows orbital vessel motion with stable work platform. Side and Bottom views also show 6 DoF work volume that the work platform center-of-gravity (C.G.) can reach.

The Robot Systems Division has been experimenting for several years with new concepts for robot cranes. These concepts utilize the basic idea of the Stewart Platform parallel link manipulator. The unique feature of the NIST approach is to use cables as the parallel links, to use winches as the actuators, and the use of gravity to separate the two platforms. So long as the cables are all in tension, the load is kinematically constrained, and the suspended platform resists perturbing forces from all horizontal lateral forces with equal stiffness. The result is that the suspended load is constrained with a mechanical stiffness determined by the elasticity of the cables, the platform sizes, and the total mass of the work platform.

During the past 2 years, NIST has been involved in the design, fabrication, and testing of "RoboCrane". RoboCrane, based on the Stewart Platform concept, has the unique feature to kinematically constrain large loads in six degrees-of-freedom even though the load (including the work platform) is suspended by cables. The concept of using six cables with their lengths controlled by winches, as opposed to six linear actuators, provides a large work volume and a large payload to weight ratio while kinematically constraining the load.

The RoboCrane controller allows the operator to “fly” the platform through the air in order to do work. Recently, NIST and Subsea International, Inc., Belle Chase, LA have been working on the S3P for subsea use. The S3P System would include a work platform, six cables/winches, sensors, and a controller. The winches and controller are located on a floating barge in the sea. Pulleys and/or winches, located at points in a triangular configuration on the barge (or on outriggers attached to the barge) provide a Stewart Platform cable configuration attached to a work platform submerged beneath the barge. Figure 2 provides front, side and bottom views of the S3P and figure 3 shows one cable/channel of six of the S3P as used in an underwater pipe repair application. By controlling the lengths of the cables, the work platform will move relative to the barge. While the barge is susceptible to wave motion, the work platform can remain in a stable position by controlling all six cable lengths simultaneously.

A NIST study using a one-dimensional test stand demonstrates how a cable-suspended load can be stabilized while giving a sinusoidal input to the cable support mechanism. By solving the kinematics of the Stewart Platform the stability of a work platform suspended by cables is also possible. Motions of the barge are at a low frequency so that it is possible to control the work platform in a stable position for a variety of wave conditions.

Typical natural periods of motion for a cargo laden vessel are about 6 to 10 seconds for heave, pitch, and roll [8]. Hence, typical winch speeds of approximately 60 m/min. are necessary to maintain a level work platform with heave amplitudes of 3.3 meters peak to peak.

Using ballast tanks attached to the work platform, the platform buoyancy can be controlled. To submerge the work platform, the ballast tanks are filled with water. At the desired work platform depth, the ballast control system is used to adjust the tension in the cables and to achieve the desired stiffness.

The work platform stability is limited by cable angles, ø, with respect to the z-axis. This angle should not be less than about 6° for optimum work platform stability [1]. This limits the working depth to the following relationship:

$$\text{Max. Working Depth} \leq 5 \times \text{Upper Platform Side Length.}$$

Therefore, a 14 m upper platform (separation distance of barge pulleys) is feasible for depths up to 70 m (see figure 2). By scaling up the dimensions of both the upper and work platforms, an S3P system can reach a depth of over 100 meters from a sea vessel while still constraining the platform in all 6 DoF.

By attaching the S3P to a partially submerged barge, the barge could be positioned at a level beneath wave crests and allow for smoother control of the work platform suspended beneath the barge. Waves would break on/over the barge and only slightly affect the motion of the barge. In this case, harsh weather conditions would not limit the use of the S3P.

The platform can be made of sealed steel tube sections, to provide compartments used as the ballast tanks, and welded into a triangular structure. Air-line fittings, electrical water/air flow valves enter each tank to provide the necessary water/air mixture. The valves are controlled from the S3P controller located on the barge. At the vertices of the steel tube work platform are eye-hook attach points for the six winch cables suspended from winches on the barge.

If very deep Stewart Platform applications are necessary, two scenarios are possible: 1) a subsea vehicle could suspend the work platform like a robot arm beneath the vehicle, or 2) sea surface control is possible by separating the upper platform support points to larger distances than proposed here. For example, three barges with each carrying two winches can be separated several hundred meters to achieve depths of 1 km or more.

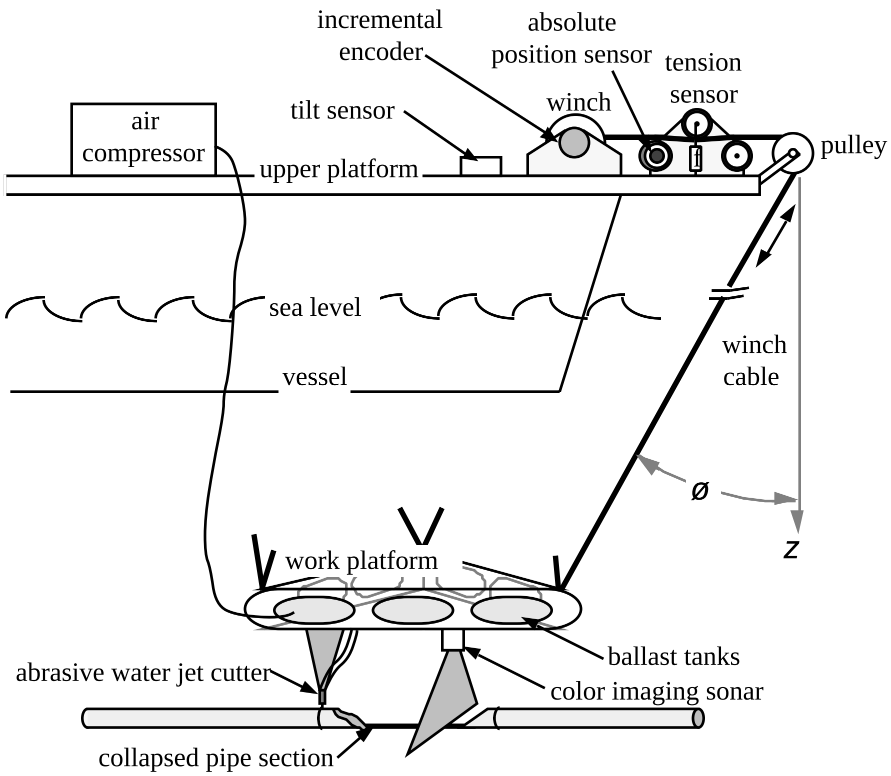

Figure 3 - Component diagram of the S3P showing one of six cables/channels and applying the S3P to underwater pipeline inspection and repair.

3. S3P CONTROL

Figure 4 shows a proposed control system for the S3P. The S3P controller monitors upper platform position information, angle and buoyancy sensors, and platform tools/sensors, for real-time feedback to the controller. This information can be processed fast enough to allow for sea surface condition updates and maintain work platform stability. For example, while the vessel heaves in one direction, the work platform compensates for vessel motion by moving the platform in the exact opposite direction. Hence the work platform stays "fixed" in that location.

By using vessel navigation systems, such as: sonar, global positioning system (GPS), or some other sea bottom sensor, the vessel position can be determined and fed into the S3P control system for work platform positioning. By anchoring the vessel and using propeller- powered station keep, the vessel moves in a small area with respect to the work site area. Once vessel position is achieved, S3P can begin doing work. S3P work platform work-volume can be generalized to include the volume mapped out by the work platform center-of-gravity within an inscribed cylinder projected below the upper platform cable suspension lines and limited by the winch cables becoming 6° or less with the vertical axis. Hence, the work volume is large enough to maintain 6 DoF control for a variety of subsea tasks and with small intended vessel movement.

Using a 6 DoF joystick aligned along the reference axis of the work platform, the operator updates the work platform position relative to the upper platform. The operator can maneuver the work platform by simply pushing the joystick in the desired direction. The rate is determined by the operator force on the joystick. Automatic work platform control is also possible if sonars and/or cameras fixed to the work platform can give the computer real-time sensor feedback. By reading a sensor array for work platform position and orientation, the computer then generates the correct control signal to move the work platform based on previously stored work platform trajectories. Therefore, simple pipe cuts/fits are possible by giving a pipe orientation and cut/fit position. By feeding this vector information into the controller, work platform reference frames can be shifted to the particular gripper, pipe-flange, cutter, etc. that is to be used.

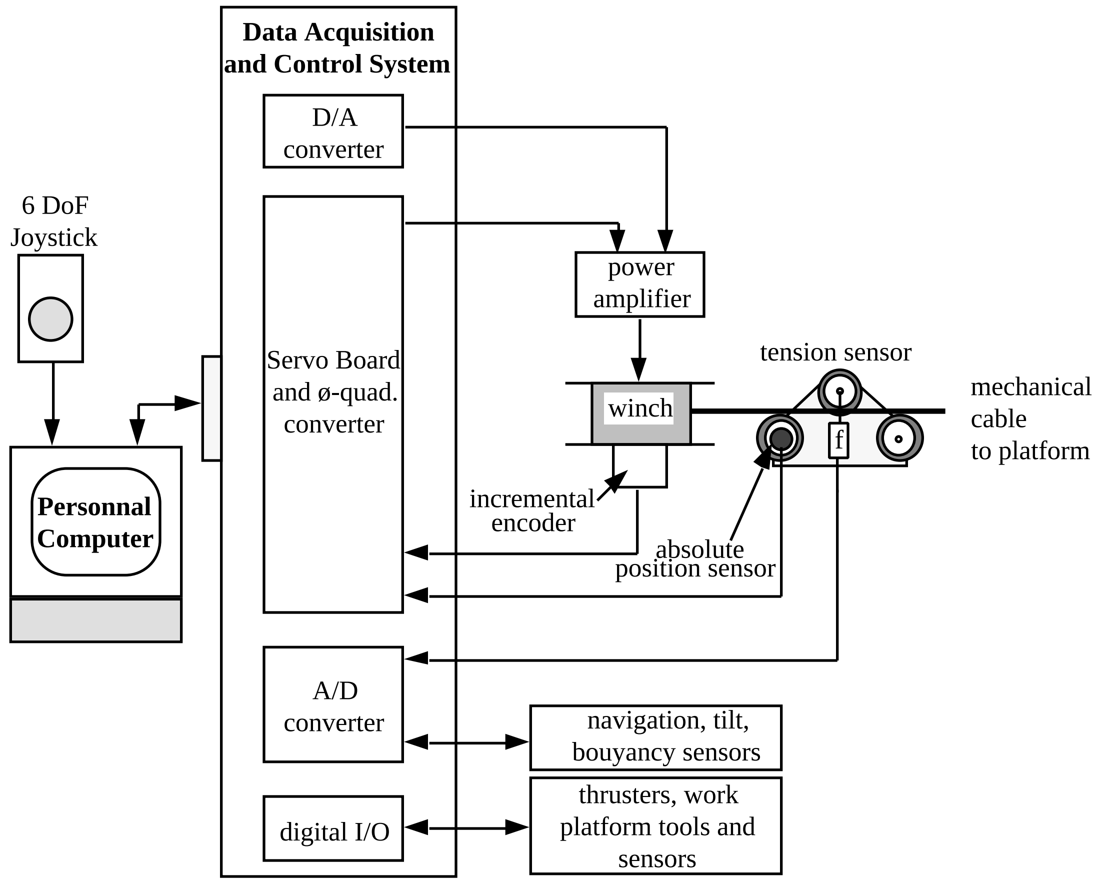

Figure 4 - Block Diagram showing One of Six Channels of the S3P Control System

4 ADVANTAGES AND DIFFERENCES

At present, cranes lift and maneuver loads underwater with one dimensional control from the crane or vessel. S3P would provide 6 degrees of freedom work platform control for doing work only presently provided by gantry fixtures attached to the sea bottom or by Remotely Operated Vehicles (ROV). Although ROV's have great dexterity and mobility, they have a small payload to weight ratio.

The S3P can provide a rigid work platform suspended from a surface barge for a variety of applications. Such as: pipe/cable laying, gripping, fixturing, cutting, positioning; inspection; salvage; hoisting; and off-shore barge/ship-hull work. Also, the work platform can be suspended from a drilling rig for rig inspection or subsea work below the rig.

5. SUMMARY AND CONCLUSIONS

Two models of the Robocrane have been designed and constructed. A two meter model has been used to test mobility issues. A six meter model has been used to test lifting and load positioning parameters and to analyze the size and shape of the work volume. Experiments were done on the Robocrane to measure payload, work volume, and platform-movement precision. A mass of 455 kg (approximately equal to the Robocrane mass) was maneuvered by the Robocrane platform while in manual mode. The load was carried to the limits of the work volume until cables began to go slack. An experiment to show platform-movement precision and stability was done with a chain saw attached to the work platform. A depth of cut to within 1 mm resolution could be made in a solid oak log. Deep cuts could also be made with ease even while driving the tip of the chain saw blade directly into the oak log.

The use of a Stewart Platform, while suspended from cables, has proved to be stable, dexterous, easy to use, and provides a high lift-to-weight ratio with a large work volume. Similar performance is possible underwater. The S3P solves the problem of current floating-vessel suspended apparatus that can only be used with sea bottom contact, with self-propelled vehicles, or by building rigs. The S3P can provide a stable work platform for a variety of underwater tasks with a minimum of sea-bottom stir-up, even while suspended from a sea-going vessel.

NIST believes that the S3P is ready for design and fabrication. Future S3P work will include building a working prototype jointly with an industrial partner. Implementation phases would include scaled-down prototype fabrication for test in a large water tank, followed by fabrication of a full-scale S3P for test in sea conditions.

6 REFERENCES

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