The Application of Advanced Robotics and Sensor Technologies to the Preservation of the USS Constitution

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ABSTRACT

The application of robotics and advanced sensor technology to solve important problems in the fields of architectural, archaeological and art conservation and preservation is discussed. The USS Constitution is considered as a demonstration project of this work. Three important applications of this technology to the preservation of the ship are discussed. A design is presented for one of these applications -- a keel deflection measurement system. It is concluded that robotics and advanced sensor technology offers substantial promise of having important benefits for the restoration and preservation of important historic and architectural sites and moments.

INTRODUCTION

This paper reports on a research program in which we are exploring the application of recently developed technologies in robotics, sensors and real-time computers to solve important problems faced by the architectural, archaeological and art conservation and preservation communities.

Over the past decade, significant advancement has been made in the technology of robotics, sensors and computers, at substantial costs to government agencies such as NASA, the Department of Defense, and the Department of Energy [1-7]. This technology has important potential application in the area of preservation and conservation of historic and artistic treasures, and in particular monuments and field sites.

Among the tasks that the conservation community is called on to perform, there exist a number that could greatly benefit from the application of advanced robotics and

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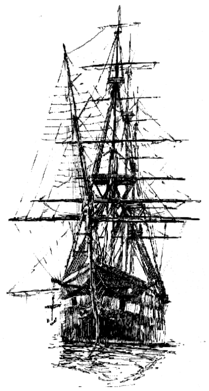

Figure 1. The USS Constitution

sensor technologies. Some traditional conservation work has resulted, unavoidably, in the deterioration of the site. For example, conservation work on some large monuments has used scaffolding anchors installed in holes drilled into the monument itself. Some conservation tasks, such as detailed site mappings, require a great deal of tedious work. Many tasks are limited due to safety considerations. Indeed, some tasks that are of interest to the conservation community simply are now impossible or impractical to execute due to safety concerns and access limitations. Finally, many highly desirable conservation procedures are simply too expensive using current techniques. Advanced robotics and sensor technologies may be able to solve some of these problems.

Working with researchers and practitioners in the conservation and preservation fields has made it clear to us, that while technical capabilities are very important, the acceptance of robotics and sensor technology to these fields will require a highly successful and visible demonstration project. From our studies, we have identified the USS Constitution as the ideal site for such a demonstration project. Our preliminary work has shown that there are a number of potential tasks, important to the preservation of the ship, that advanced technology could perform more effectively than current methods. In some cases the technology could offer greater safety or is potentially more cost effective. In this paper we describe three of these potential applications and their possible solutions. The first is an automated in-situ hog measurement sensor system to continuously monitor the shape of the ship's keel while she in the water. The second is a robotic system to detect rot in the ship's internal structure beneath its rock and chain ballast. The final is a robotic device to inspect the ship's mast and rigging for deterioration.

It should be recognized that a demonstration on the USS Constitution would also benefit the growth of robotics. It would provide a challenging and exciting test-bed for the technology under actual field conditions.

HOG MEASUREMENT SYSTEM

The keel of the ship changes shape over time due to the effects of water and loading. In order to reduce this hog and thereby extend the life of the keel, it is necessary to know the shape of the curve accurately. Presently, hog measurement methods include using divers who manually measure the displacement of the keel from a fixed reference line, or indirect methods from inside the ship's hull. We have developed a system based on distributed sensor technology for quickly, accurately, and inexpensively determining the keel shape. Simply put, the system measures the water pressure at a small set of locations (seven) on the keel. From these measurements a computer accurately infers the shape of the keel, in real-time.

The system is able to use a small number of sensors by applying Chebyshev theory to determine the optimal locations for the pressure measurements. These locations are selected to minimize the maximum measurement error. The water pressure on the keel is converted to an air pressure signal by fixed keel pressure transducers, see Figure 2. Pressure sensors then measure the pressure at the keel, which is a direct function of the depth. These pressure sensors are exposed only to air pressure and are located at an on-board measurement computer within the ship. This design puts all electronic hardware elements in a “shirt sleeve” environment. It permits the use of inexpensive commercial components and makes maintenance and calibration of the system easy.

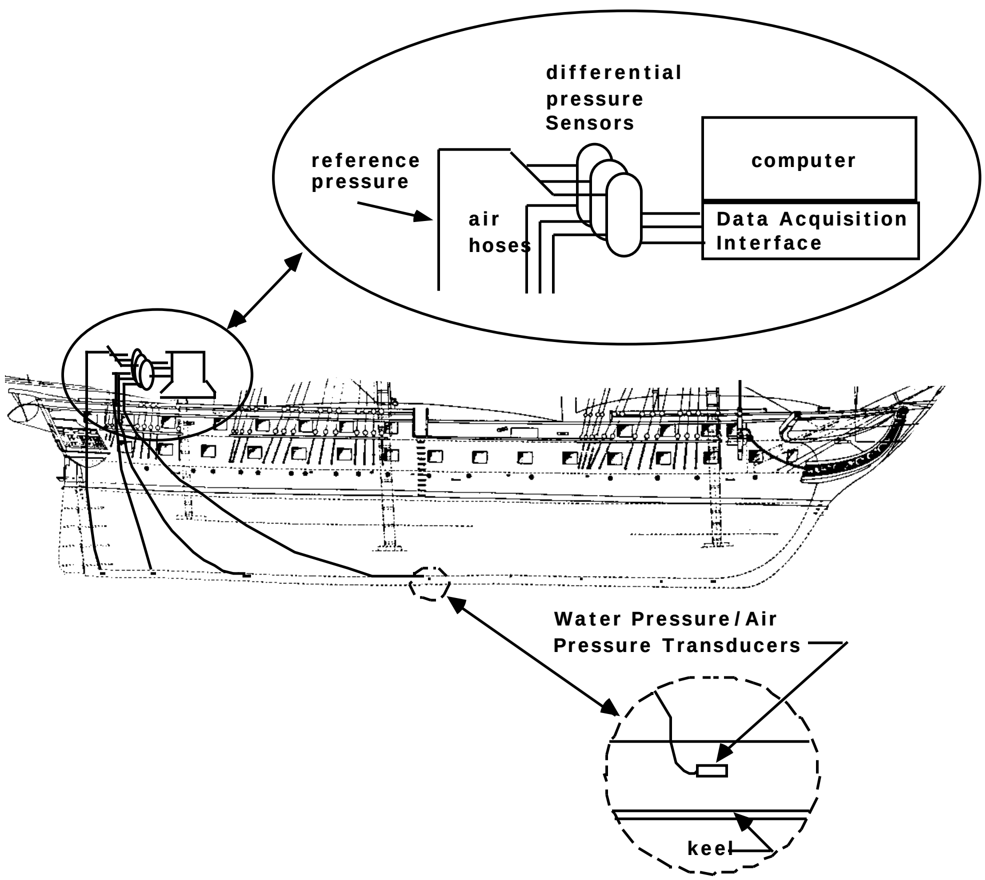

Figure 2. The Hog measurement system overview. Sensors on the keel report pressure at specific locations, from which the computer calculates the keel shape.

The keel pressures are compared to a reference pressure at one end of the ship using these differential pressure sensors. This allows accurate measurements over the small range of transducer depths. From these finite depth measurements the computer calculates the shape of the keel, see Figure 3.

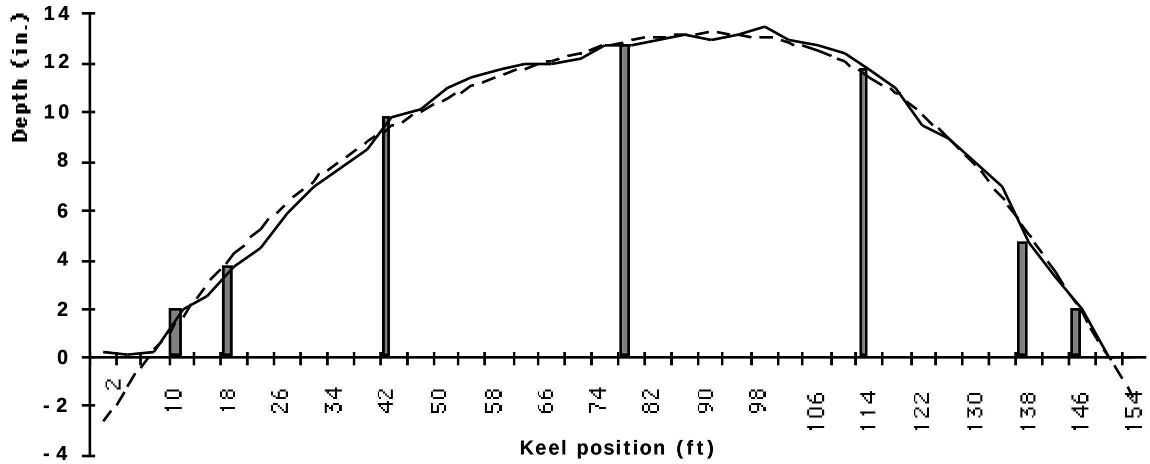

Figure 3. Keel shape inferred from seven measurements. The bars are sensor readings, the solid line is diver-measured data, and the dashed line is the curve shape inferred from the sensors.

SUB-BALLAST INSPECTION

The area underneath the ballast in the hold of the ship is subject to damp, rot-inducing conditions, see Figure 4. It is impossible for workers to inspect this area except during dry-dock, when the ballast is removed. In order to facilitate more frequent inspection, the use of a small autonomous field robot to perform this inspection is being considered, see Figure 5. The robot would carry a video camera and sensors designed to detect and measure rot.

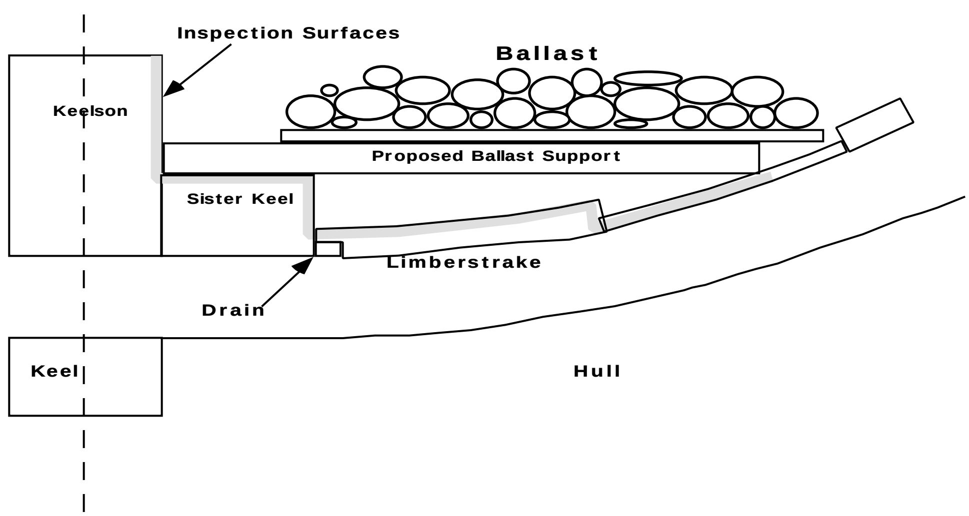

Figure 4. Sub-ballast area. The area is only exposed during dry dock. An automated inspection system that can work underneath the ballast would be very useful.

The inspection task is further complicated by the presence of diagonal riders, which periodically cut off sections of the sub-ballast area. The robot would have to climb out of the area, over the rider, and then back down into the next section.

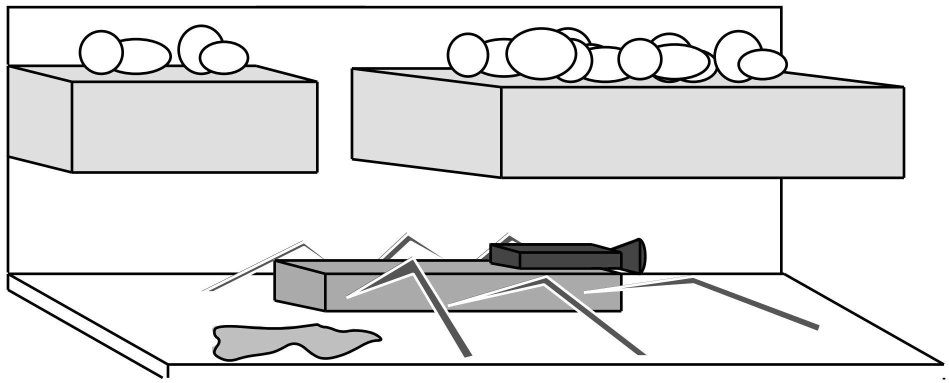

Figure 5. A concept for a sub-ballast inspection robot.

Various aspects of this problem are being studied, include rapid mechanical robotic design, robust planning algorithms, advanced sensor technology, and control systems. The results of this work would be useful in a wide variety of field applications, including other conservation tasks.

MAST AND RIGGING INSPECTION

Finally, the masts of the ship are also subject to rot and need periodic inspection. The current inspection method has a worker climb to extreme heights, and/or expensive (and unsightly) cranes to inspect the upper sections, see Figure 6. The topmost sections are never inspected. A robotic solution might again be useful.

We are examining two approaches to this problem, see Figure 7. First is a climbing robot concept to navigate the complex rigging and climb the masts. This approach challenges present technology. However, we have developed a simple climbing robot and are studying its potential extension to such tasks as mast inspection. The second approach is long reach manipulators, see Figure 7. Problems relating to the control of long reach flexible manipulator systems are similarly under study in our laboratory in connection with NASA's Space Station Freedom.

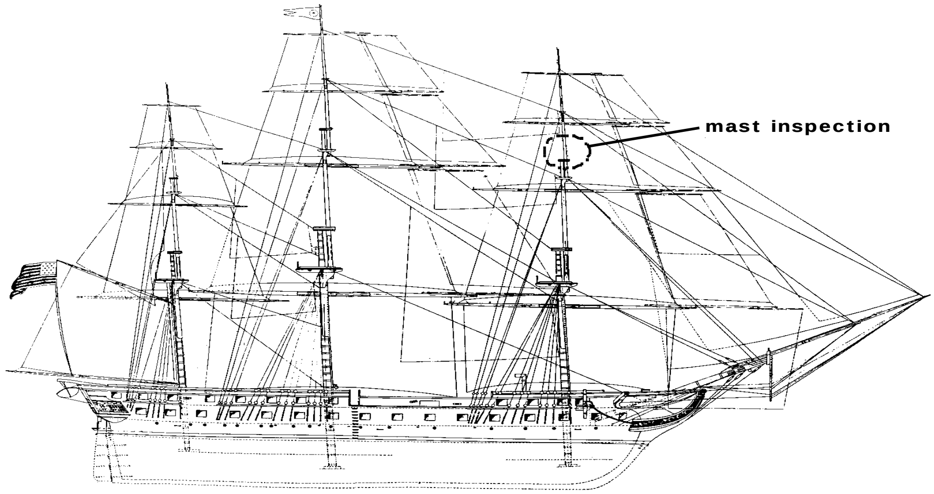

Figure 6. The complexity of the Constitution's rigging and height of her masts (220') make inspection difficult.

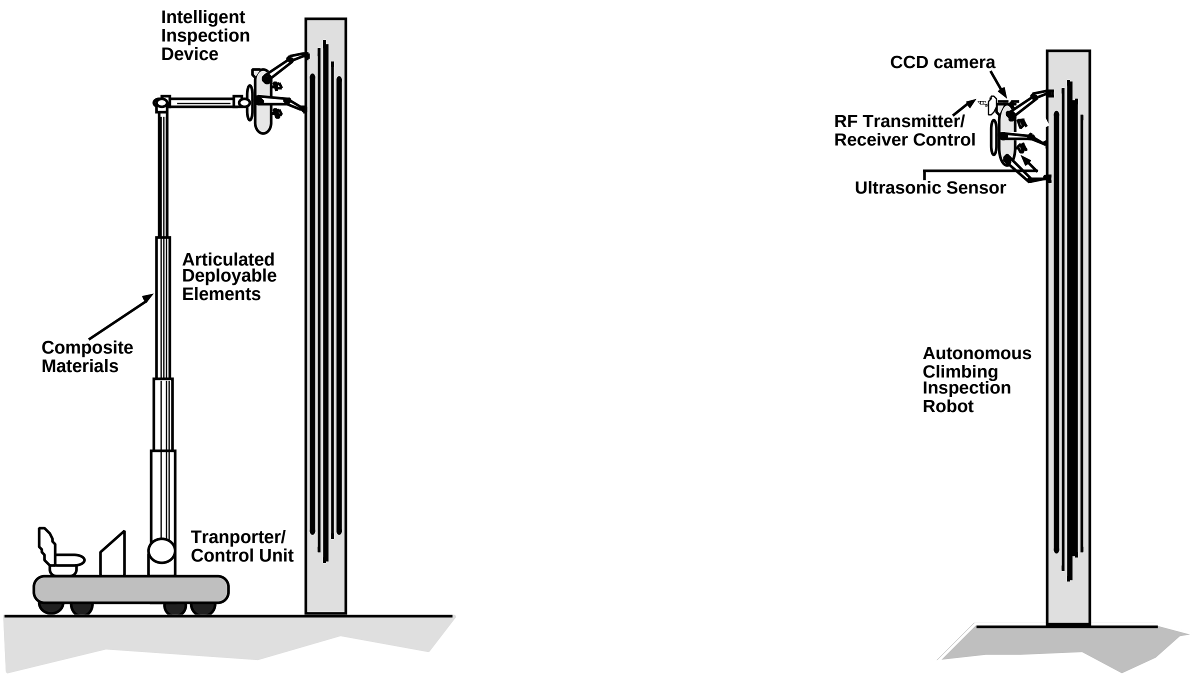

Figure 7. Two mast inspection robot concepts

CONCLUSIONS

This paper reports on a research program to explore the application of robotics, sensors and real-time computer technologies to solve important problems faced by the architectural, archaeological and art conservation and preservation communities. The USS Constitution identified has been identified as the ideal site for a demonstration project of this work. This paper describes three potentially important applications of this technology to the preservation of the ship.

We believe that such advanced technology could perform these tasks more effectively, safely, and with less total cost than current methods. A conclusion of our work to date is that robotics and advanced sensor technology could have an important impact of the field of the restoration and preservation of important historic and architectural sites and monuments.

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