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Portable Robot for Scour Survey Below Highway Bridges

William R. Bath

Sonsub Environmental Services, 10905 Metronome, Houston, Texas 77043-2202

Abstract

The robot is designed to remotely survey streambed conditions around underwater bridge foundations. Operating from the bridge deck, the operator can quickly and easily inspect the area under the bridge and around the underwater foundations for scour damage. Scour is the term used by bridge engineers to describe erosion of the streambed around bridge pilings and piers. Erosion of this type has resulted in the catastrophic failure of many bridges.

The robot has a 60 ft. (18 m) long telescoping manipulator arm that reaches over the side of the bridge to place a sonar probe in the water under the bridge (Fig. 1). The operator on the bridge deck uses a small joystick control to sweep the arm parallel and perpendicular to the roadway to cover the entire inspection area. A 386DX computer on the robot automatically records the position of the probe and the depth of the water at each data point. The data file collected by the robot can be displayed in spread sheet or contour map format for use by the bridge engineers to determine the safety margin of the bridge foundations.

1. INTRODUCTION

Flowing water is a force of nature that can be channeled and harnessed for human needs but it can never be completely controlled. As demonstrated by the recent flooding of the Mississippi River in the U.S.A., we can only fight a holding action to force the river to go where we want it to go. The constant flow of river water around underwater bridge foundations is bad enough during normal times but during flood stage conditions the river has the power to destroy the bridge. Natural soil erosion and changing current conditions can lead to significant soil loss around the pilings. During periods of flooding, when the water flow is abnormally fast, large quantities of streambed soil can be washed or scoured away in a very short time. Scour holes detected around bridge foundations have been known to expose or completely undermine the piles below the pier footings. Rivers running at flood stage velocities can erode large amounts of streambed material is a very short time. In addition, scour holes normally fill up with sediment as the flow subsides leaving no visible trace of their existence. Traditional underwater inspection methods, normally involving scuba divers and small boats, cannot be used in flood stage conditions to determine if the bridge is safe for continued use. This robot is designed to demonstrate remote methods of underwater bridge inspection.

2. ROBOT DESCRIPTION

The robot inspection system is battery powered and completely self-contained. The robot's trailer-mounted manipulator is hydraulically operated to provide

60^{o} of movement parallel to the bridge deck, 30^{o} out from the deck and 15^{o} underneath the bridge. On a bridge 50 ft. (15 m) above the water, the robot can inspect an area 50 ft. (15 m) wide from 15 ft. (4.5 m) underneath the bridge to 25 ft. (7.5 m) out from the bridge deck (Fig. 2).

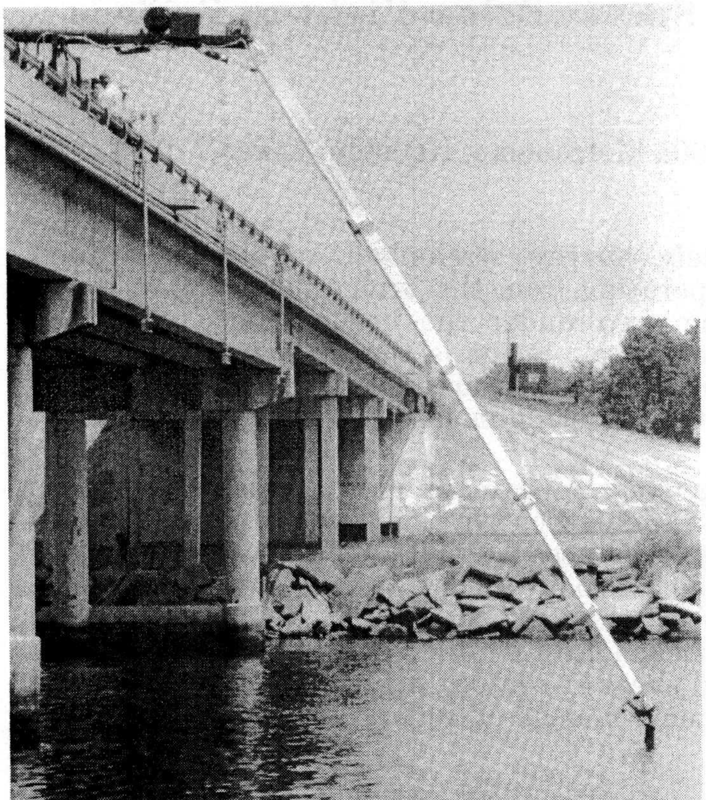

Figure 1 Robot on the Bridge Deck Surveying the Streambed

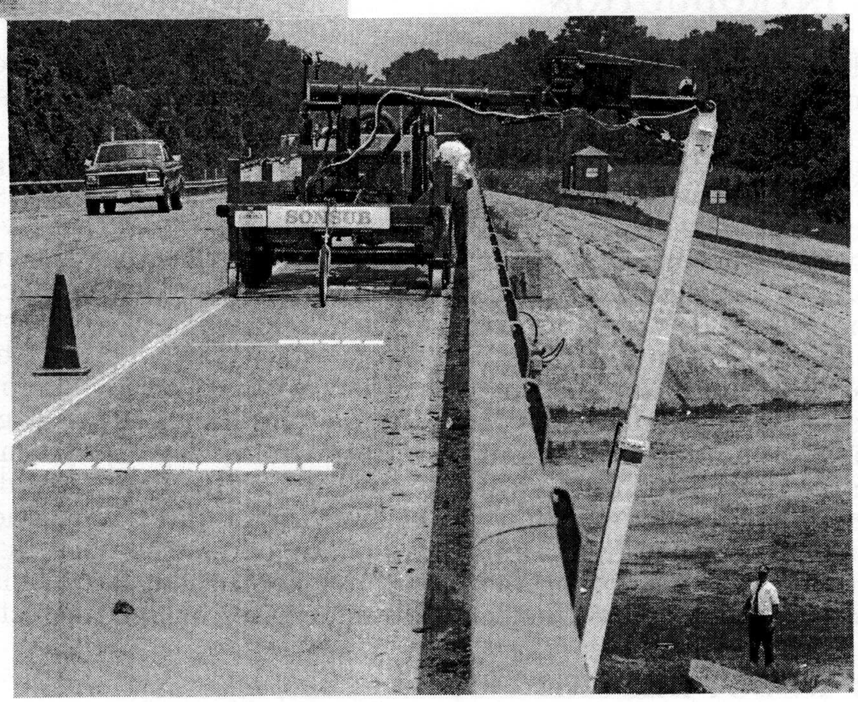

Figure 2 The Robot's Manipulator Arm Extended Underneath the Bridge Deck

The manipulator arm is gravity extended and cable retracted by a variable speed electric winch. The winch is operated by the robot's computer to automatically maintain the vertical position of the probe. A joystick control commands the robot's computer to operate the variable rate hydraulic functions that move the arm. An onboard, rechargeable battery pack supplies the power to operate all the functions including the hydraulic pump, the winch and the computer. Manually adjusted steel rollers on each corner of the trailer frame provide a stable base for inspection operations. With the manipulator folded for travel, the robot is 8 ft (2.4 m). wide, 25 ft. (7.6 m) long and 8 ft. (2.4 m) high (Fig. 3). The trailer configuration was chosen so that the system could be towed with a highway department dump truck.

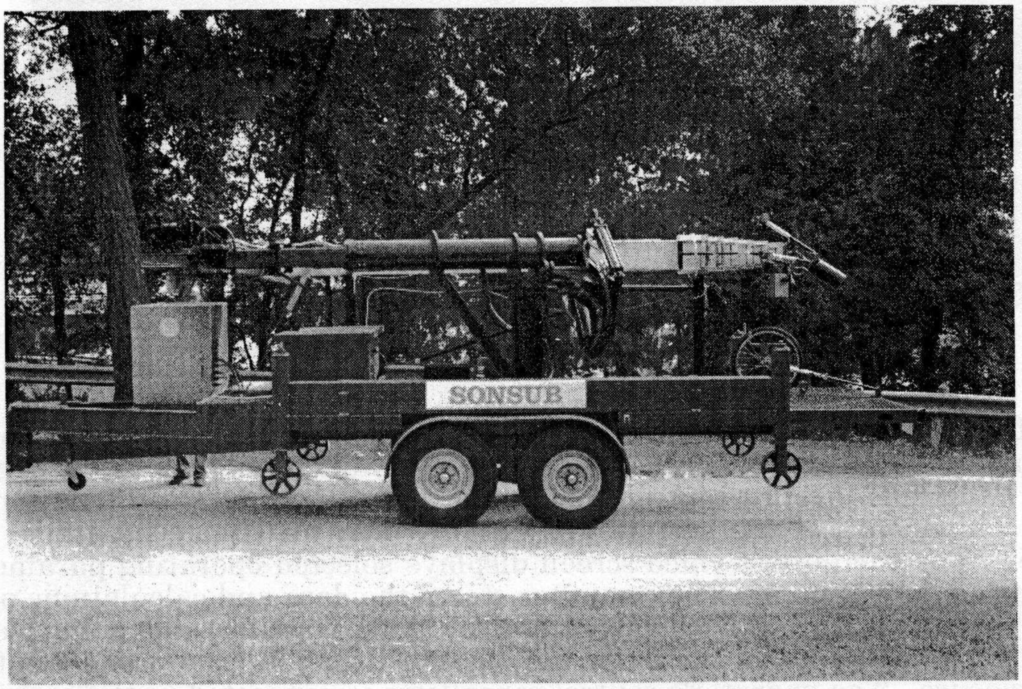

Figure 3 Robot Folded for Travel

The robot inspection system also features an inclinometer, odometer, and a dry land altimeter to record a profile of the bridge and the land below it. The bridge profile, the position of the sonar probe and various sensor values are displayed on the computer screen in real time. The sonar position display maintains a visible track of the probe travel to verify complete coverage of the inspection area. A standard computer keyboard is provided to allow the operator to keep field notes in the computer memory.

The system can be operated in both scour survey and bridge profile modes. For scour survey inspections, the operator rotates the arm over the side of the bridge (Fig. 4) and extends it down until the sonar probe on the end of the boom enters the water. The probe is automatically controlled to project about 6 in. (15 cm) into the water surface. The 6 in. (15 cm) diameter probe pierces the surface of the water by only a few inches so that hydrodynamic drag is minimized. Two electric linear actuators keep the probe pointed straight down during operations.

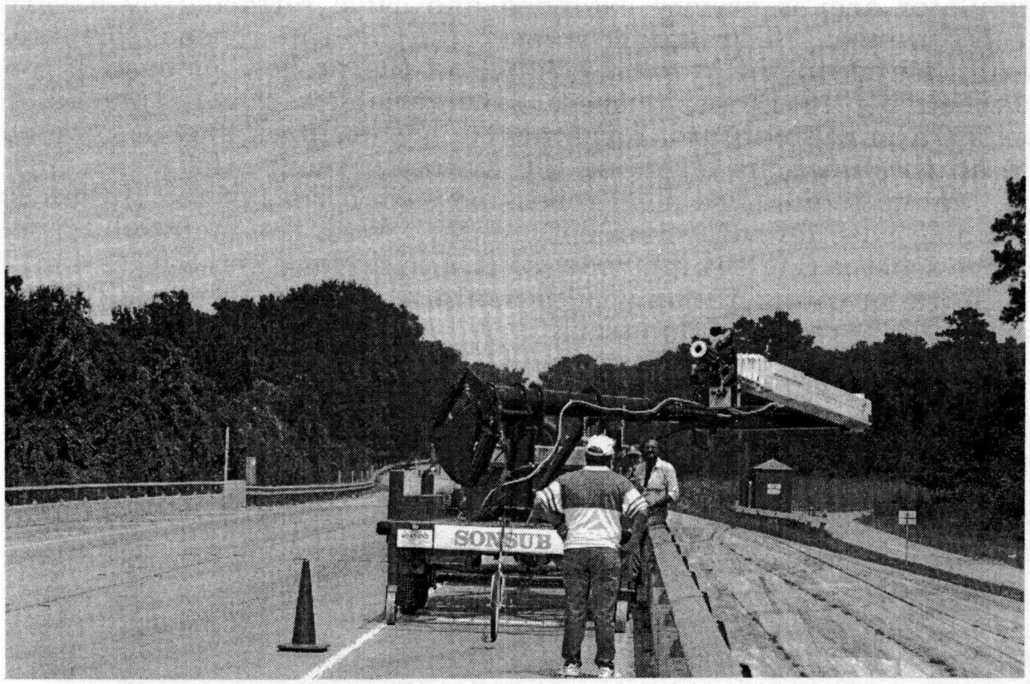

Figure 4 Extending the Arm Over the Side of the Bridge

The 60 ft. (18 m) long telescopic boom is hydraulically operated by a 24 volt dc power unit. The five function, flow regulated hydraulic system is operated from a small, hand-held joystick control. Electronic angle and rotation sensors on the various components of the system are connected to an IBM compatible 386 computer. The computer's video screen displays selected operating parameters and collected data (Fig. 5). The computer stores the data and calculations on an internal hard disk. A 3.5" floppy drive for data transfer and a mouse for operating the mapping software are also included in the computer's weather-tight enclosure. The operator's control consollette is connected to the computer by a 15 ft. (4.6 m) tether to allow the operator to stand at the bridge rail during operations. The consollette also has position and water depth displays that enable the operator to maneuver the probe around submerged objects and other areas of interest.

The operator uses the joystick control to sweep the boom under the bridge, around the foundation and across the inspection area. The computer keeps track of the position of the probe and records the water depth at each point. The data file collected can be displayed in spread sheet format or as a contour map (Fig. 6). In bridge profile mode, a calibrated trailing wheel odometer keeps track of the system's position as it is towed across the bridge. An acoustic distance sensor mounted on a separate boom measures the distance to the land and water surface below the bridge. A inclinometer on the trailer frame measures the inclination of the bridge. The computer records this data and displays a profile of the bridge on the computer screen and logs it into the computer memory. Scour survey and bridge profile can be conducted simultaneously so that one trip across the bridge will produce a complete data file.

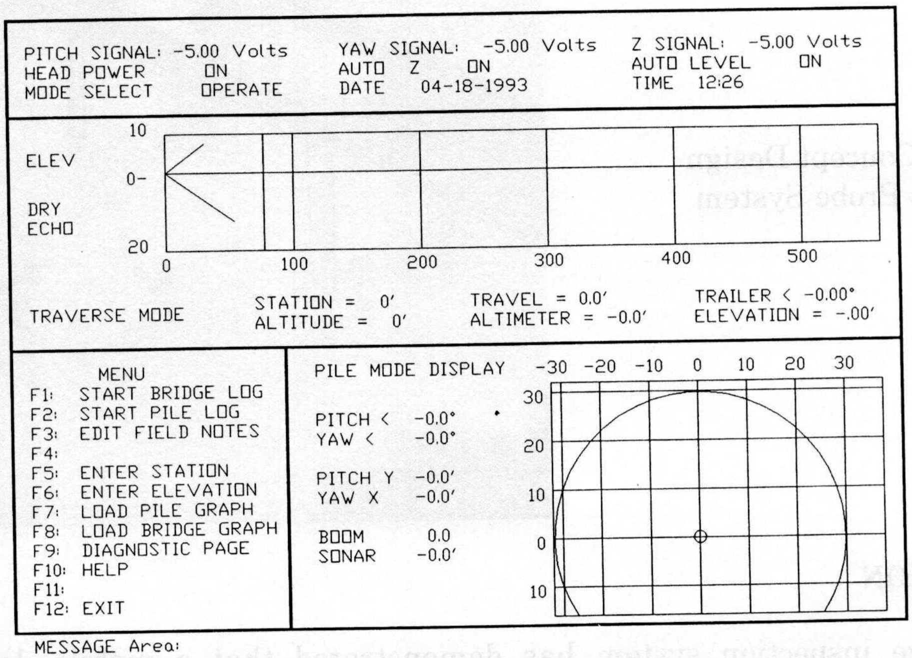

Figure 5 Computer Display Format

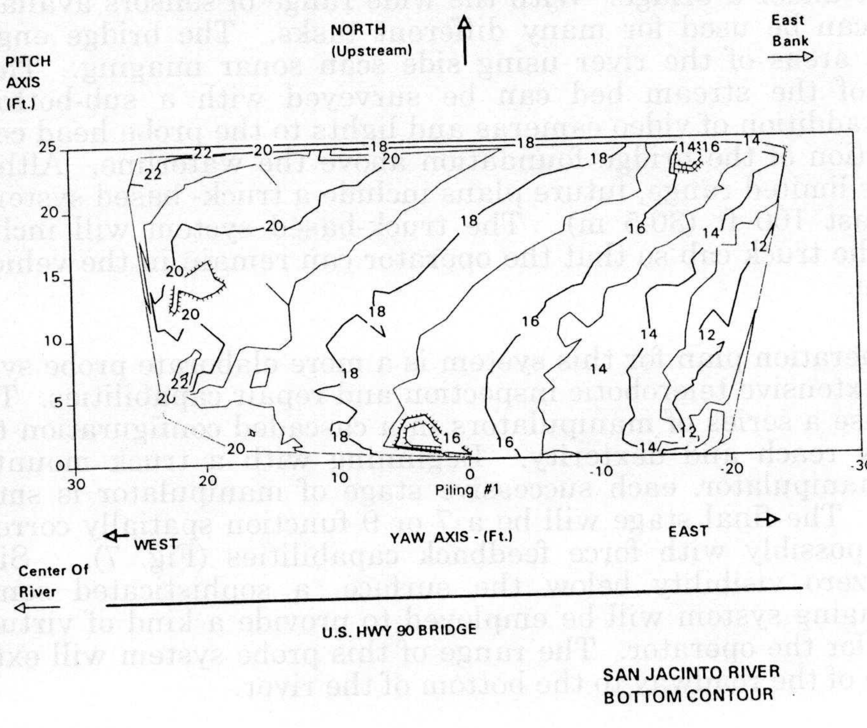

Figure 6 Contour Map of the Streambed

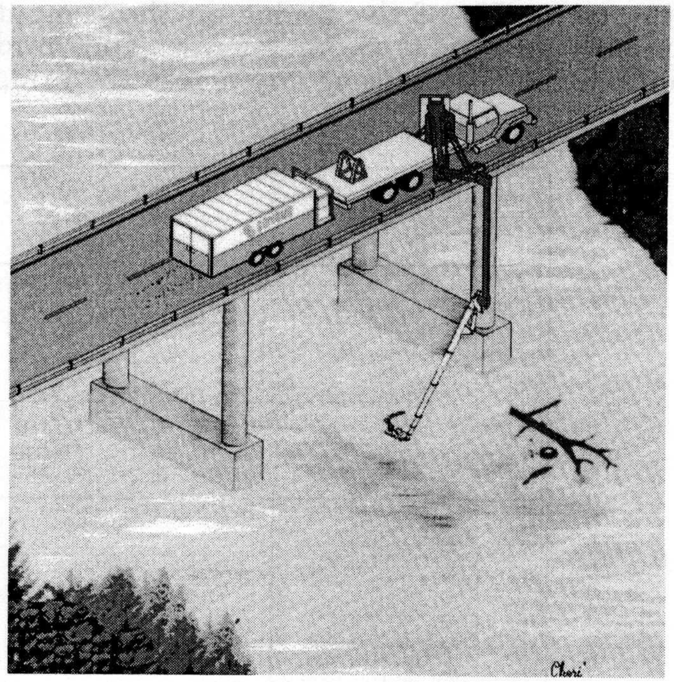

Figure 7 Concept Design for Future Probe System

CONCLUSION

This bridge inspection system has demonstrated that a mobile, long reach robotic manipulator can easily and accurately place an electronic probe in the flowing water under a bridge. With the wide range of sensors available today, this system can be used for many different tasks. The bridge engineer can inspect large areas of the river using side scan sonar imaging. The relative composition of the stream bed can be surveyed with a sub-bottom profile system. The addition of video cameras and lights to the probe head can provide visual inspection of the bridge foundation above the waterline. Although this prototype has limited range, future plans include a truck- based system with an arm of at least 100 ft (30.5 m). The truck-based system will include video monitors in the truck cab so that the operator can remain in the vehicle during the inspection.

The third generation plan for this system is a more elaborate probe system that will provide extensive telerobotic inspection and repair capabilities. This probe system will use a series of manipulators in a cascaded configuration to provide the necessary reach and dexterity. Beginning with a truck mounted, gross positioning manipulator, each successive stage of manipulator is smaller and more precise. The final stage will be a 7 or 9 function spatially correspondent manipulator possibly with force feedback capabilities (Fig. 7). Since most rivers have zero visibility below the surface, a sophisticated sensor-based computer imaging system will be employed to provide a kind of virtual reality environment for the operator. The range of this probe system will extend from the underside of the roadway to the bottom of the river.