Development of a Robotic Bridge Maintenance System

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Abstract

This paper will expand on the Rrobotic Bridge Maintenance Ssystem (RBMS) developed by the Construction Automation and Robotics Laboratory (CARL) at North Carolina State University (NCSU). The system consists of a 4-degree-of-freedom robot designed and built at NCSU mounted on the end of a truck mounted peeper crane. Additionally, a containment system is mounted in front of the robot to contain the toxic waste created by the removal of the lead-based paint from the bridge beams and trusses.

1: Introduction

Robotic systems for construction applications have advanced dramatically over the past few years. Automated systems were initially developed to reduce labor requirements, shorten construction time, reduce costs, and improve quality. Currently, benefits such as moving workers out of the dangerous work areas and conformance to agency standards such as those set by the Environmental Protection Agency (EPA), the Toxic Substance Control Act (TSCA), and the Occupational Safety and Health Administration (OSHA) have improved the workers' environments and improved worker morale.

Steel bridge painting operations are dangerous and hazardous to human health. A typical maintenance operation involves sandblasting the bridge surface to remove old paint and rust, and then painting to protect the surface from the environment. This work is performed manually using a scaffold or similar device to access the work areas which must be completely encased due to the lead content in the paint. Heavy equipment and protective clothing are also required. The protective clothing that workers wear is very hot, especially in warmer climates. This leads to rapid fatigue and workers have to break at regular intervals to regain their strength.

Workers are exposed to not only the harmful paint components such as lead, but also to the risk of falling. According to the National Safety Council, seventy percent of all serious injuries to coating workers are caused by falls. Strenuous working conditions and worker fatigue contribute to an inconsistent quality of the applied painting. This hazardous painting procedure is well suited for automation techniques.

Development is justified by the potential improvements in safety, quality, and productivity. With the robotic bridge maintenance system, human operators will be removed from the dangerous work environment location under the bridge deck to a safe place on top of the deck. There they can teleoperate the robotic system without risking their health or their lives. The quality of painting is also improved because the robotic system does not suffer from exhaustion or fatigue as a human operators does. A consistent, high quality painting is then obtained. By protecting the worker from hazardous environments productivity is greatly increased.

Other systems which have been developed include the Aerial Platform developed by the California Department of Transportation. [3] This system only performs the inspection of the bridge. Another system is the Robotic Trunk System developed by the FHWA Research and Development Division. [5]

With help from the Federal Highway Administration (FHWA) and the North Carolina Department of Transportation (NCDOT), the Construction Automation and Robotics Laboratory (CARL) at North Carolina State University (NCSU) has successfully developed a prototype robotic bridge maintenance system. The system consists of a modified Peeper crane with a robotic arm and containment system attached to the end. The system has the capability to perform contained sandblasting, painting, and spray washing of bridge I-beams and bridge bearings. From an economical standpoint, it is practical to have one robotic system to do all of these jobs. The focus of this paper will be to present an overview of the developed system and highlight its advantages and potential

2: Overview of System

The robotic bridge maintenance system has four main capabilities: remote inspection, spray washing, paint removal, and painting. The original prototype of the system was developed and successfully tested as a robotic bridge paint removal system August of 1994. The basic goals of the system were to eliminate the need for a human to be involved directly in the removal process and to contain the lead-based paint. (A schematic of the original system is shown in Figure 1 and a picture of the system in action is shown in Figure 2.)

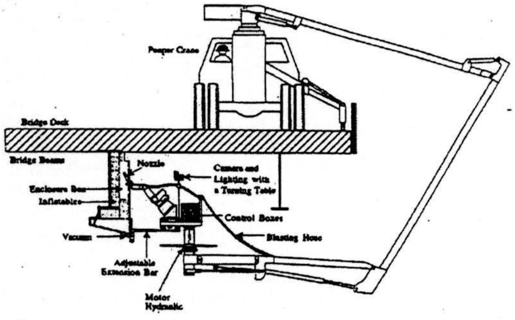

Figure 1: Schematic of Robotic Bridge Paint Removal System

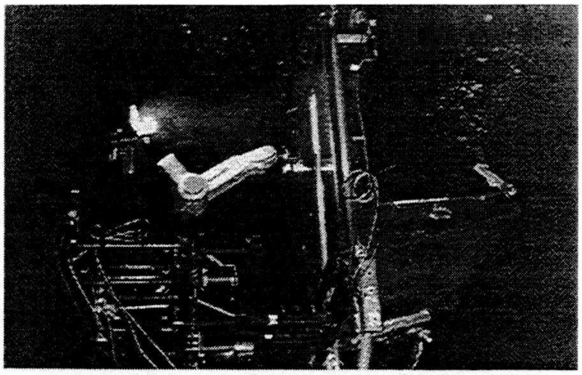

Figure 2: Robotic Bridge Paint Removal System During Field Test

The system has been since upgraded to perform other tasks. The robot which was used has been changed. The new robot was designed and fabricated at NCSU. It is a hydraulically actuated four degree-of-freedom robot mounted on a gantry table attached to the end of a peeper crane which is tested at a bridge test facility at the NCDOT. (see Figure 3.)

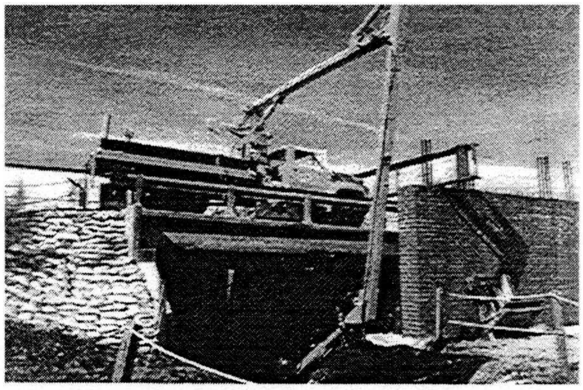

Figure 3: Peeper Crane with Robot Deployed under Bridge Test Facility

The procedure to implement the RBMS begins with the deployment of the crane. If a CAD drawing of the bridge is available, the crane can be deployed autonomously via an overlay algorithm and information from the encoders mounted to each of the joints on the crane. Alternatively, if a CAD drawing of bridge is not available an operator can tele-operate the crane by using the vision system which is part of the system. The vision system consists of two cameras: one mounted on the arm of the robot as shown in Figure 4 and a second camera placed at a distance on the bridge perpendicular to the plane created by the crane.

Once the crane is deployed underneath the bridge, a sonar system, consisting of sonars mounted to the crane boom, the robot, and the containment system, is used to position the robot within an acceptable range to the bridge beam. The acceptable range is defined by the work-space of the robot. An articulated platform onto which the robot's gantry table is mounted is used for final positioning so that the containment box can be placed flush against the web of the bridge beam.

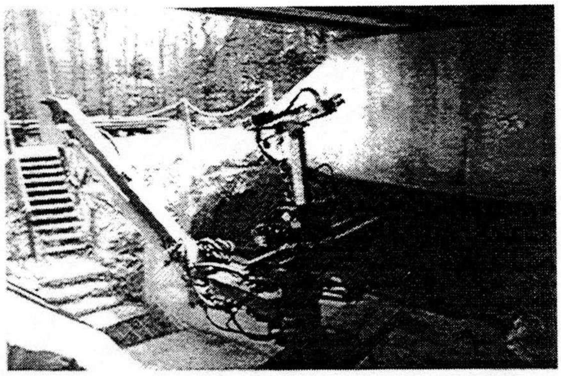

Figure 4: Maintenance Robot Deployed under Bridge Test Facility

With the robot positioned under the bridge, the maintenance procedure can proceed. The first step is the inspection process. Using the camera mounted on the robot's arm the operator can inspect the beam for spots which need to be repaired/cleaned. The advantage of placing the inspection camera directly on the robot instead of using a pan-n-tilt unit is the elimination of having to transform information from the camera's coordinate system to the robot's system.

The robot can now be controlled to spray wash, sandblast, and/or paint the beam. The system uses currently available tools for the different procedures. A gripper mounted to the wrist grips a universal attachment which mounts to the individual tools, i.e. the robot grasps the individual tools in the same manner. A tool table is in the process of being designed to allow the operator to change tools with the robot.

The following sections will describe the individual parts of the robotic bridge maintenance system in more detail.

3: Control of the System

The control of the system can be divided into two parts: control of the crane and control of the robot. It is possible to control the crane and the robot individually or at the same time.

3:1 Crane Control

Since the bridge maintenance process has been robotized in an attempt to improve safety and health conditions, automation of the crane is desired. Because of the highly unstructured nature of the environment, it is desirable to use a tele-robotic mode of control instead of a fully automated mode. The control of the crane is based on a graphic path planner which creates the manipulator path from a starting position to a desired destination in a CAD environment. [2] The path planning supports a graphic overlay control which allows for a tele-robotic mode of operation.

Off-line path planning provides a basis for on-line crane control in the tele-robotic mode. Predetermining the crane path generates the required control data for the deployment of the crane under the bridge.

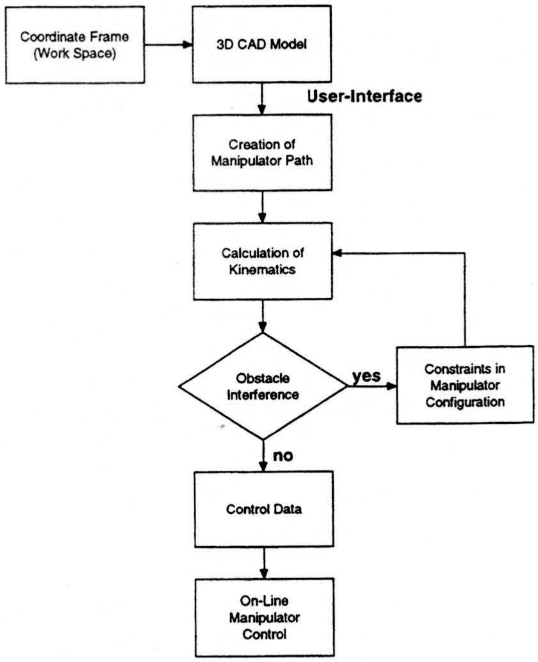

Figure 5: Graphic Based Off-Line Path Planning

The graphic based path planner is built in a graphic environment of CAD for efficient tele-robotic operation of the manipulator as shown in Figure 5. The CAD integration allows for a user-interface to determine the proper trajectory. The trajectory is then drawn in a coordinate system developed for the working environment depicted as a Bezier curve. The path from the starting position to the finish position is divided into a number of via-points. Through the use of inverse kinematics, the planner calculates the proper joint angles to move the manipulator to the next via-point. The capability of collision avoidance is available because of the tele-robotic mode and the real-time manipulator control.

3.2: Robot Control

The robot control is a closed loop system with feedback from the robot's actuators back to the computer. The rotary and linear actuators have positional feedback, from the actuator-mounted potentiometers, routed through Cyclon STC's (signal tracking controllers) with PID adjustments. The proportional valves operating the actuators allow the mechanical means of implementing the PID functions needed for smooth movement. Opto brain and bus boards were used to communicate between the STC's and the host computer, a Pentium 90 running Win95. These analog/digital and digital/analog converters allow the PC bus board to properly address the signals for communication between the Opto equipment and the PC. The control equipment needed to be together in a single location due to the need for parallel communcation. For this reason, a common containment box was built to hold all equipment including power supplies, controllers, etc.(as shown in Figure 6.)

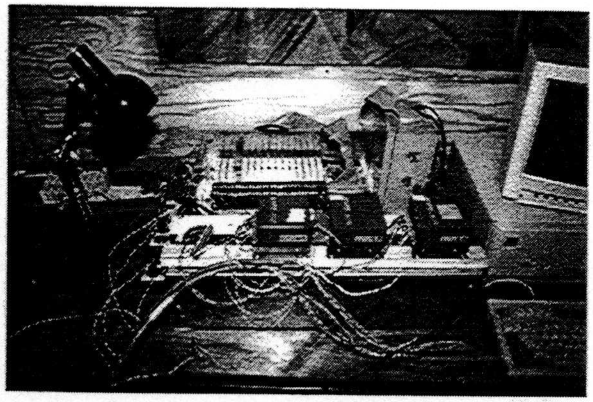

Figure 6: Picture of the Control Hardware

The control algorithm which was written to control the individual actuators, the address locations, and the data lines was written in MS Quick Basic 4.5. Since information from all of the inputs (feedback lines) and outputs was available to the computer, it was possible to accurately control the motion of the robot.

The motion of the robot is controlled through the algorithm which calculates the inverse kinematics for each of the via-points. There are also pre-programmed motions to cover application areas for painting and sandblasting. These motions are all integrated with the motion of the gantry table to increase the work-space of the robot.

4: Containment System

Since the system will be used to remove lead-based paint from bridge I-beams, a method of containing the toxic debris was needed. The initial design of a containment box (Figure 1) was completely redesigned for RBMS. The new design consists of two smaller, more flexible containment boxes as shown in Figure 7.

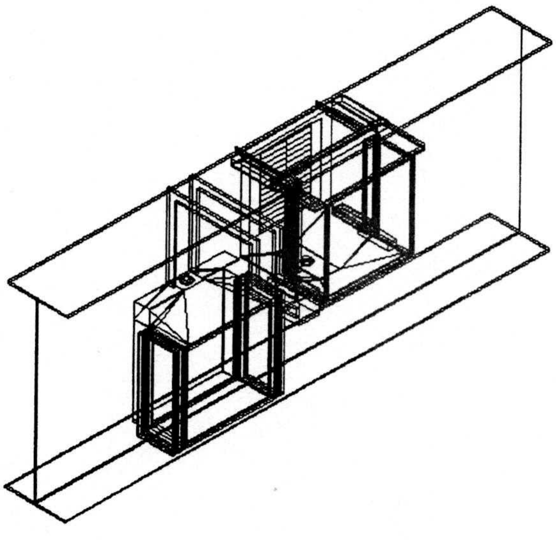

Figure 7: CAD Drawing of Containment System

The dimensions of the new containment boxes are 18"x23"x7" and they have the capability of of clamping around the flanges of the I-beams by using a hydraulic actuator. This capability allows the system to be used to remove paint from trusses. Nylon brushes are used to create seal the boxes against the beam and a vacuum system removes the dust and lead into an environmentally safe container.

5: Maintenance Tools

The maintenance procedure is accomplished by using the robot to manipulate existing tools. The tools presently used are a high pressure spray washer, a sandblast nozzle, and a paint nozzle. The motion that the robot needs to perform for the individual tools is quite similar. For sandblasting and spray washing the path speed and distance from the surface are not critical, but for painting they are.

Painting is the critical operation defining the needed precision of the arm movement. Specific tolerances are given for the different paint layers from primer to top coat. These are controlled by nozzle to surface distance, nozzle speed across surface, and air pressure for spraying. The first two conditions are controlled by the programming and the third is determined by an air pressure regulator set for the given paint, adjustable at the truck. From the truck the air line is run down the boom of the crane along with the needed paint line.

The coating thickness and appearance are used to measure the quality of steel bridge painting. The parameters which were used for painting process planning are: 1) the spray gun angle, 2) the air pressure, 3) the fluid pressure, 4) the distance from the paint nozzle to the surface, and 5) the moving speed. These parameters were found to have a strong influence on the coating thickness and the appearance. [1] Lab experiments were conducted to determine the optimal values for different bridge features which were created to represent the steel bridge. Each feature corresponds to a set of optimal values of the process planning parameters. Using these optimal values to set up and move the spray gun, the specified quality can be achieved.

The spray gun which was used was a Graco AA3000 automatic air-assisted airless spray gun. The air lines and paint lines were run along the crane boom and attached to a paint source and an air compressor mounted on the bed of the truck.

For pressure washing, a high pressure water line was installed along the beam attached to a 3200 psi pump mounted on the bed of the truck. The universal gripper is capable of picking up the pressure washer wand and washing the desired areas of the bridge beam.

6: Conclusion

This paper has describe the development of the Robotic Bridge Maintenance System jointly developed by the NCDOT and CARL at NCSU. The system allows an operator to be removed from the dangerous environment under the bridge and allows him/her to tele-operate the entire bridge maintenance procedure.

One of the major advantages that this system has over others is that it has been designed as a relatively simple modification to existing equipment. The gantry table and robot mount to the peeper crane with four bolts and four quick connect lines. This also has the advantage of making the system easy to transport.

Another advantage is the use of a robot to do the bridge maintenance procedure. By using a robot and a universal gripper, virtually any type of blasting method can be used. Additionally the robot can be used for other types of applications in which a tool needs to be manipulated and it is desirable to place the worker at a safe distance.

7: Acknowledgments

The authors wish to acknowledge the support of the North Carolina Department of Transportation and the Federal Highway Administration for funding the research. Special thanks goes to the workers at the Bridge Maintenance Facility at the Raleigh Depot for all of their help.

The authors also wish to acknowledge Schunk Precision Workholding Systems, Inc. for their gracious support.

8: References

[1] Bai, Y. and Bernold, L.E., (1996). "Development of a Robotic Bridge Painting System," The Second Conference on Robotics for Challenging Environments, Albuquerque, NM, June 3-6, 1996, pp. 185-191.

[2] Moon, S. and Bernold, L.E., (1997). ASCE Journal of Computing in Civil Engineering, Vol. II, No. 2, pp. 113-120.

[3] Woo, D. (1995). "Robotics in Highway Construction and Maintenance," Public Roads, FHWA, US Department of Transportation, Winter issue, pp. 26-30.

[4] Wu, Randolph, and Renyu (1996). "A New Robotic Trunk for Highway Maintenance," Research and Development Division, FHWA, McLean, VA.