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Development Of A Robotic Bridge Maintenance System

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Abstract

This paper describes the research and development of an automated paint and rust removal system for steel bridges. The system's ultimate objectives are to lessen human exposure to harmful and dangerous material (such as paint particles, asbestos, rust, and/or lead), free up workers from labor-intensive jobs, and minimize bridge maintenance expenses. The robot is equipped with many Non-Destructive Evaluation (NDE) detectors and a navigation control system that enable it to go around the bridge deck accurately and independently. This allows the robot to gather visual data and conduct NDE assessments. The suggested robotic system may enable faster and more economical completion of the data collection and inspection of the bridge deck. For efficient bridge deck observing, a crack detection method is covered in depth and used to create the deck crack map. The robot gathers data on ultrasonic surface waves (USW), impact-echo (IE), and electrical resistivity (ER). Following processing, these data are utilized to produce maps of the bridge deck's corrosion, delamination, and cement elastic modulus. There includes a full discussion of the robot design process, main research topics, auxiliary technology, and the creation of systems. Included are a review of some important concerns and an overview of the research's current state.

Keyword: Ultrasonic Surface Waves, Impact-Echo, Electrical Resistivity, Non-Destructive Evaluation.

1 INTRODUCTION

Worldwide transportation infrastructure cannot exist without bridges. In India, there are more than 30,000 rail and road bridges. One of the biggest expenses in the creation and upkeep of transportation infrastructure is bridge repair or replacement. Steel bridge failure is mostly caused by corrosion, which can be reduced by painting the steel framework. The cost of doing routine inspections and maintenance on these bridges is high because of the risks to the environment and worker health and safety. The two steps involved in maintaining steel bridge coatings are repainting and rust/paint stripping.

Grit-blasting is a practical and efficient way to remove paint off huge surfaces, but this is also where the main issue resides. Grit-Blasting is the most costly operation required for steel bridge maintenance, and it is also the most labor-intensive and dangerous. In addition to handling pressures of 100N and more for extended periods of time, workers must take safety measures to prevent exposure to dust that contains dangerous substances. Since the full extent of the acknowledged toxicity and long-term health implications related to lead and asbestos are just now being discovered, it is imperative that all bridge repair activities be conducted in secrecy to avoid pollution of the environment and possible health dangers to the general population. Therefore, using robotic tools to augment manual labor in grit-blasting will have a major negative influence on people's health, safety, and finances.

1.1 System Design

A 6-degrees-of-freedom (DOF) industrial robot, a mobile platform, a sensor pack with cameras, a capacitive network sensor, a laser rangefinder, and a powerful computer are the main components of the proposed robotic system (Figure 1a). The response force from the blasting nozzle requires a comparatively big robot to manage. The entire system is set up on the totally enclosed scaffold's floor. The system must function “in three modes: manual, semi-autonomous, and autonomous.”

1) A Manual mode: this mode is used to test and clean the most complex parts of the system that cannot be automated.
2) In the partially autonomous mode, the gadget has the ability to autonomously blast a predetermined zone, such as a particular beam face. Using the map created during independent travel and map building, the operator can select this location remotely.
3) Autonomous mode: By detecting and mapping the surroundings, determining the areas that need blasting, and creating routes for the grit-blasting nozzle that respect operational limitations, this mode enables the system to autonomously grit-blast an unfamiliar steel structure (Figure 1b). The security of the system will be guaranteed by real-time collision avoidance and detection technologies and procedures. To accomplish automated operation, significant research questions need to be answered in the areas of sensor development, material type recognition in bridge structures, exploration and 3D mapping of complex structural surroundings, robot route and movement planning, and collision detection. A thorough testing procedure will be put in place in both lab and on-site settings to assess the study's results.

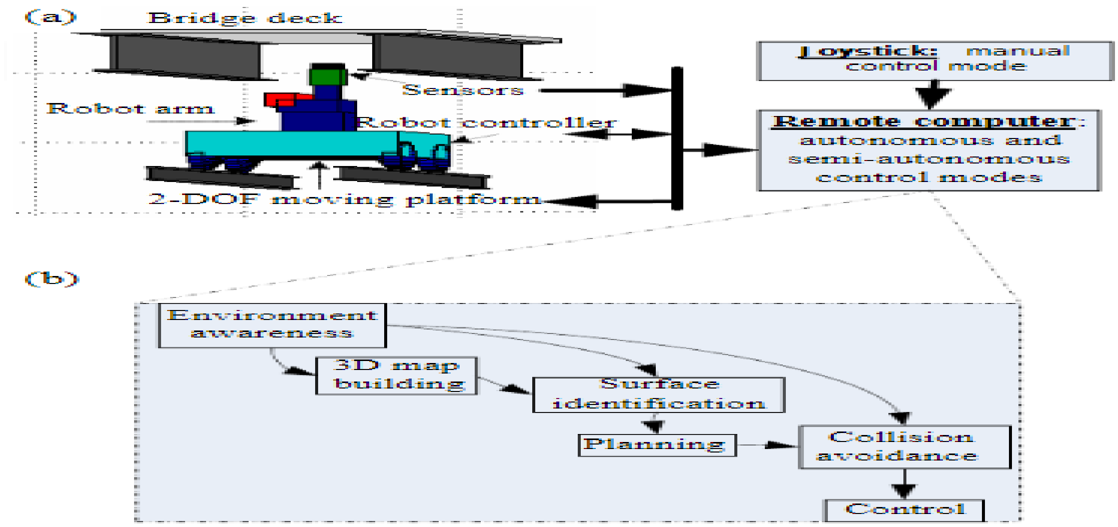

Figure 1 (a, b)- System design of a self-sufficient robotic grit-blasting system for maintaining bridges.

1.2 Material Type Classification

Steel components including I-beams, timber walkways, concrete, plastic pipes, etc. make up bridge constructions. Determining the target sites and substance kinds is essential to avoiding harm to non-metal building components. The task is made easier by the goal of identifying only metal and the narrow range of substance types found in bridges; however, the identification process is made more difficult by the intricate design of the bridge, the intricate geometrical shapes of its parts that support it, and numerous the composites that are comprised of different material types.

1.3 Robot Path and Motion Planning

Once the environmental map is created and the locations to be blasted are determined, the blasting nozzle path and robot movements are created. Robot arm and support platform movement should be kept to a minimum, productivity should be maximized, and the grit-blasting coverage should be as thorough as possible through path and motion design. Coordinating the blasting of structural component edges to safeguard nearby non-metal objects and partitioning a sizable area (perhaps with irregular boundary forms) are additional design concerns.

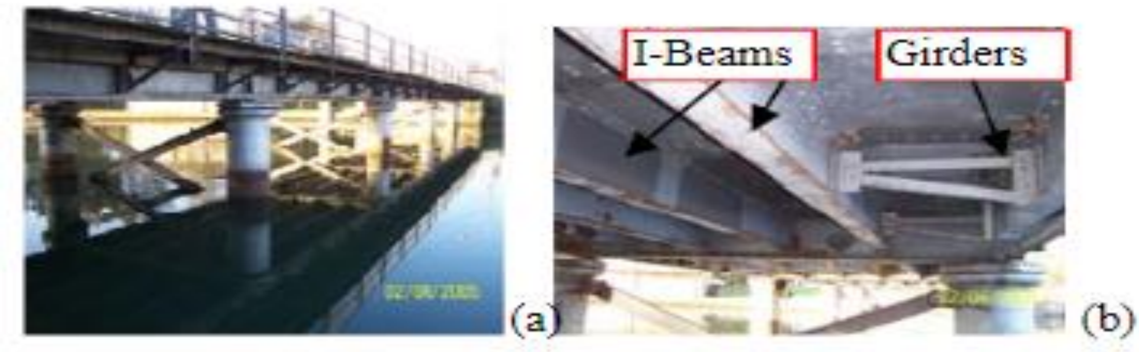

Figure 2-(a) An example bridge; (b) Part of the bridge structure

1.4 Collision Avoidance

Crash or Collision avoidance is a critical problem because of the grit-blasting environment's intricacy and the robot's big size in relation to the surroundings. The autonomous operation includes collision avoidance at several stages:

1) Conducting surveys and mapping. Since this is the first time the robot is observing and interacting with its environment, it has no awareness of what is around it. In order to avoid any collisions with the surrounding environment, exploration algorithms are required.
2) Phase of making preparations. The robot has just now completed a 3D map of its immediate vicinity. In order to maximize efficiency and create collision-free pathways for the whole robot arm, sophisticated planning algorithms are necessary.
3) This is the rough patch. If the robot follows the intended collision-free trajectory and velocity, it should run into no problems during grit-blasting. Even if the robot fails or the environment suddenly changes, a collision control system based on sensors and algorithms must be in place to prevent accidents.

2 EFFICIENT METHODS FOR COLLISION AVOIDANCE

Collision avoidance and identification during grit-blasting and mapping is an important yet challenging topic that must be handled. The robot has just a little understanding of the geometry of the preservation environment when it first enters the space. Because of this, sensor package exploration requires the ability to detect robot body impacts with the environment. A capacitive sensor for collision detection has already been designed, and a sensor network is now being installed around the robot's arm to forecast crashes [6-9]. During grit-blasting and mapping, avoiding collisions and identifying objects is a crucial yet difficult problem to address. The robot has just a vague idea of the layout of the region it will be maintaining at initially. Therefore, the ability to recognize body-environment interactions is crucial when employing a sensor package to discover the world around a robot. There is already a very sensitive sensor in place, and work is underway on a sensor network to place around the robot arm to forecast potential collisions. Figure 4 depicts the distance query technique used to find collisions using spheres that include the robot and its surroundings [10].

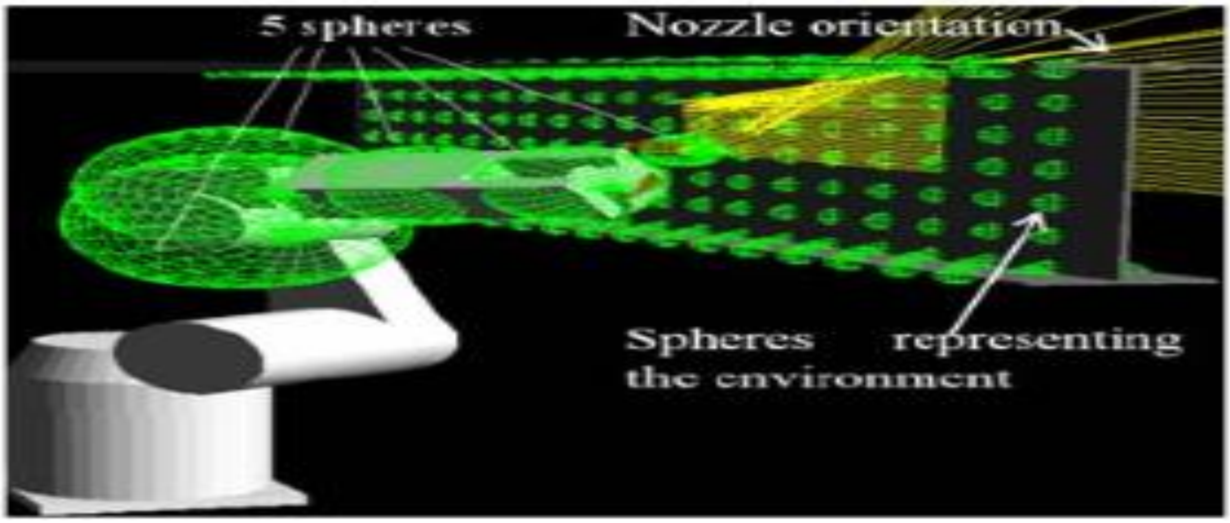

Figure 4. Collision Avoidance

For grit-blasting collision avoidance, the use of a three-dimensional force field (3D-F2) method" has also been investigated. With complex blasting settings, this technique successfully prevents collisions for the 6DOF manipulator while preserving the intended nozzle path and speed. A repellent force is generated in the robot kinematic as well as dynamics studies when the manipulator movements and its hemispheric force field comes within a specific range of an impediment.

In order to keep bridges in good condition, grit-blasting methods need a consistent speed at which the blasting spot "moves" along the predetermined route on the surface. The duration and trajectory of the blasting stream may be modified during grit-blasting operations. Therefore, the blasting stream is considered an additional connection, and a spherical joint is used to unite the blasting surface to its terminal. Results from a number of simulations demonstrate that the 3D-F2 is able to successfully avoid collisions and keep the nozzle on its intended trajectory throughout complicated blasting situations.

Figure 5-A prototype system and a mock-up section of a bridge structure.

2.1 Challenging Development Issues

There are several design and production activities in this project. Creating an automated grit-blasting system prototype is the most significant and difficult task. This development entails the integration of the autonomous robotic system's functional components—such as sensing, map construction, planning, and so forth—as well as the system's integration with grit-blasting machinery. Although there is still work to be done, a lot of progress has been achieved. The platform and a modelled portion of a bridge construction are depicted in Figure 5. An industrial robot is mounted on a platform and supported by rails so that it may travel across the bridge's framework.

3 CONTROL OF THE SYSTEM

The system control may be separated into two components: the robot control and the crane control. Both the robot and the crane may be controlled separately or simultaneously.

3.1 Crane Control

Automation of the crane is desired as the bridge maintenance process has been robotized in an effort to improve safety and health conditions. Using a tele-robotic way of control is preferable to a completely automated mode due to the very unstructured nature of the environment. A graphic path planner, which generates the manipulator route from a starting point to a desired destination in a CAD environment, provides the foundation for the crane's control. The path planning facilitates a telerobotic style of operation by supporting a visual overlay control. The foundation for via the internet crane control in the tele-robotic mode is provided by offline path planning [12]. The necessary control information for the crane's deployment beneath the bridge is produced by predetermining the crane's path.

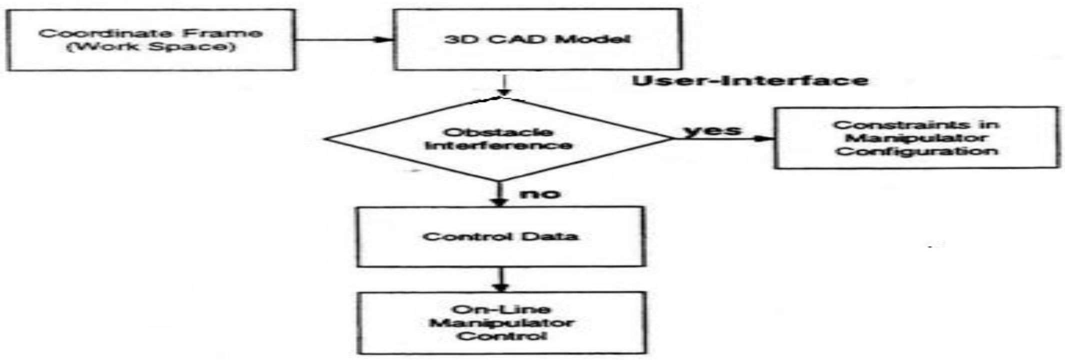

Figure 5: Graphic Based Off-Line Path Planning.

As seen in **Figure 5**, the graphic-based path planner is constructed in a CAD visual environment for effective telerobotic manipulator operation. A user interface may be used to calculate the correct trajectory thanks to the CAD integration. Next, the trajectory is represented as a Bezier curve in a coordinate system created for the work environment. There are several viapoints along the route that connects the starting and finishing positions. The planner determines the appropriate joint angles to move the manipulator to the next via-point by applying inverse kinematics. The telerobotic mode and real-time manipulator control enable the capacity of collision avoidance.

3.2 Robot Control

Robot Control is a system with a closed loop where the actuators on the robot provide input to the computer. Signal tracing controllers, or cyclone STCs, use PID adjustments to convey positioning information from actuator-mounted voltage regulators to the rotary and longitudinal actuators. The PID functions required for smooth motion are mechanically implemented via the proportional valves that control the actuators.

Due to the requirement for parallel communication, the control equipment had to be grouped together in one place. The actuators were individually controlled by the control algorithm. The data lines and address locations were developed in Microsoft Quick Basic 4.5. Additionally, pre-programmed movements covering painting and sandblasting application regions are available. To expand the robot's work area, these motions are all combined with the gantry table's motion.

4 CONTAINMENT SYSTEM

A way to control the hazardous waste was required since the technique would be used to remove lead-based paint off bridge I-beams. A containment box's original design (Figure 6) has been entirely redone for RBMS. As seen in **Figure 6**, the revised design comprises of two more flexible, smaller containment boxes.

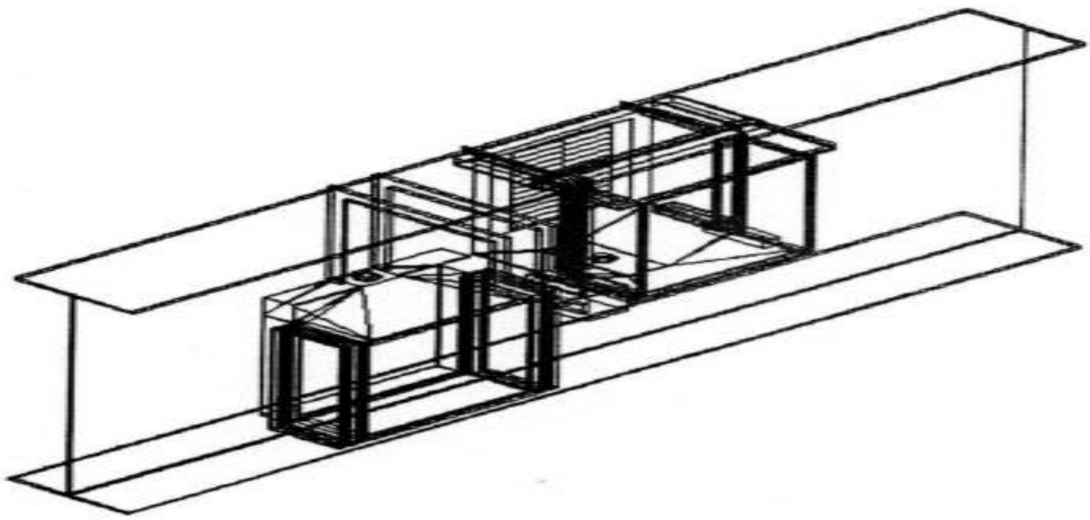

Figure 6: CAD Drawing of Containment System.

With their 18"x23"x7" dimensions, the new containment boxes may be used with a hydraulic actuator to clamp around the I-beam flanges. This feature makes it possible to utilize the system to paint truss removal. The boxes are sealed against the beam using nylon brushes, and dust and lead are collected into an environmentally safe container using a vacuum system.

4.1 Maintenance Tools

The robot manipulates the current instruments to complete the maintenance procedure. A paint nozzle, a sandblast nozzle, and a high pressure spray washer are the instruments now in use. The movements that the robot must do for each of the numerous tools are rather similar. While travel speed and distance from the surface are not important for painting, they are for sandblasting and spray cleaning. The crucial process that determines the required level of arm movement accuracy is painting. For each paint layer, from primer to top coat, there are specified tolerances. Air pressure for spraying, nozzle speed across surface, and nozzle to surface distance regulate these.

Programming controls the first two conditions, while an air pressure regulator on the truck that is adjusted for the specific paint determines the third. The air line and necessary paint line are run from the truck down the crane's boom. The thickness and look of the coating are used to gauge the steel bridge painting quality. The spray gun angle, air pressure, fluid pressure, distance from paint nozzle to surface, and movement speed are the factors that were utilized to plan the painting procedure. The thickness and look of the coating were found to be significantly influenced by these characteristics.

To find the ideal values for the many bridge characteristics that were designed to resemble the steel bridge, laboratory tests were carried out. Every characteristic is associated with a range of ideal process planning parameter values. The desired quality may be obtained by adjusting and moving the spray cannon using these ideal parameters. The paint and air lines were routed alongside the crane boom and linked to an air compressor and paint supply fixed on the truck bed. The pressure washer wand may be picked up by the universal gripper, which can then be used to clean the selected portions of the bridge beam.

5 CONCLUSION

The creation of the **Robotic Bridge Maintenance System**, a collaborative effort between various works, is described in this study. With the help of the device, an operator may teleoperate the whole bridge maintenance process, saving them from the hazardous conditions beneath the bridge. This system's main benefit over others is that it was created as a rather easy addition to already-existing machinery. Four bolts and four fast connect wires are used to secure the gantry table and robot to the peeper crane.

This has the added benefit of making the system portable. Using a robot to complete the bridge maintenance process has additional benefits. Any kind of blasting technique may be employed with a robot and a universal gripper. The robot can also be employed in other kinds of applications where it's necessary to control a tool and keeping the worker at a safe distance is preferred.

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