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Rapid and comprehensive condition assessment of concrete bridge decks using a robotic system with integrated NDE

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ABSTRACT: One of the main causes of limited use of nondestructive evaluation (NDE) technologies in bridge deck assessment is the speed of data collection and analysis. The paper described development and implementation of a fully automated (robotic) system for data collection using multiple nondestructive evaluation (NDE) technologies. The system is designed to characterize three most common deterioration types in concrete bridge decks: rebar corrosion, delamination, and concrete degradation. The robotic system implements multiple existing nondestructive evaluation (NDE) technologies for that purpose, namely: electrical resistivity (ER), impact echo (IE), ground-penetrating radar (GPR), and ultrasonic surface waves (USW). Their implementation is designed to enhance the overall interpretation through their complementary usage. The system also utilizes advanced vision to substitute traditional visual inspection. The automated data collection system is complemented by an advanced and automated data interpretation. The associated platform for the enhanced interpretation of condition assessment in concrete bridge decks is comprised of data integration, fusion, and deterioration and defect visualization. The platform specifically addresses data integration and fusion from the four NDE technologies: ER, IE, USW and GPR, and the high resolution deck surface imaging. The data visualization platform facilitates intuitive presentation of the main deterioration and defect forms: corrosion, delamination, and concrete degradation.

1 INTRODUCTION

The Federal Highway Administration's (FHWA's) Long Term Bridge Performance (LTBP) Program research team interviewed a number of state DOTs regarding the expenditure levels for maintenance, rehabilitation, and replacement of bridge decks. The conclusions of the interviews were that those constitute between 50 and 80 percent of the overall expenditures for bridges., The Program included bridge deck performance as one of the key bridge performance issues, and is for that purpose conducting periodical data collection using multiple NDE technologies (Gucunski et al., 2012 and 2013). It is expected that in the next phase of the Program decks of hundreds of bridges will be evaluated. Having the means for rapid and accurate condition assessment of bridge decks is critical for the success of the LTBP Program. Furthermore, to fully benefit from the integrated NDE approach, there is a need for interpretation techniques that can effectively integrate data from different NDE technologies and perform inferences that may not be possible from a single technology alone. Such capabilities would also benefit state DOTs through: better planning, better selection of intervention procedures, and a reduced frequency and duration of traffic interruptions.

For the above reasons, the FHWA initiated development of a robotic system of NDE of concrete bridge decks with two main objectives in mind. The first objective was to develop a system that would enable automated data collection using multiple NDE technologies. The device was envisioned to implement existing, proven NDE technologies, already implemented within the LTBP Program. The operation of the system was designed to require supervision from a single person only. In addition, it was anticipated that the system would collect data four or more times faster than the current single NDE technology devices that require a team of five people. Finally, and unlike the current practice, the proposed automated data collection system was envisioned to provide a real-time preliminary condition assessment of the bridge deck.

The second main objective of the development was to create a platform for enhanced interpretation of condition assessment in concrete bridge decks through data fusion, and deterioration and defect visualization. The interpretation and visualization platform will specifically address data integration and fusion from the four NDE technologies: GPR, ER, USW, and IE. The operation of the platform is such that it will facilitate intuitive presentation of the main deterioration caused by corrosion, delamination, and concrete degradation. Finally, and unlike the current practice of separately presenting survey results from individual NDE technologies, the proposed visualization platform integrates survey results for the condition assessment of bridge decks.

2 ROBOTIC PLATFORM FOR NDE OF BRIDGE DECKS

2.1 Hardware description

The robotic system for condition assessment of bridge decks, with its main components marked, is shown in Figure 1. The robotic platform has four omni-directional wheels. which enable the robot to move laterally and to turn at a zero radius. These wheels also allow fast movement from one test location to the next one in any direction. The system is equipped with the four NDE technologies and three digital cameras for high resolution bridge deck surface imaging and panoramic imaging of the test location surrounding.

The NDE components: ground penetrating radar (GPR) and acoustic arrays, and electrical resistivity probes, enable detection and characterization of the three aforementioned deterioration types. The two IDS Hi-Bright GPR arrays on the rear side of the robot are shown in Figures 1 and 2. Each of the arrays has sixteen antennas, or two sets of eight antennas of dual polarization. The GPR arrays' primary purpose is to do rebar mapping, measure the concrete cover, and to contribute to the assessment of the corrosive environment, concrete degradation and likelihood of delamination. Each of the two acoustic arrays on the front end of the robotic platform (Figure 1) contains multiple impact sources and receivers (Figure 2). Different combinations of sources and receivers are used for impact echo (IE) and ultrasonic surface wave (USW) testing. The primary objective of the IE testing is detection and characterization of delamination. Unlike the manual IE testing within the LTBP Program with a 0.6 m spacing between the test points, the acoustic arrays enable IE data collection with a 0.15 m spatial resolution. One the other hand, the USW test is used to describe concrete quality, by measuring the concrete modulus. Similar to IE, the acoustic arrays enables measurements at a much higher spatial resolution by using multiple source and receiver combinations. The acoustic arrays were manufactured by Geomedia Research and Development.

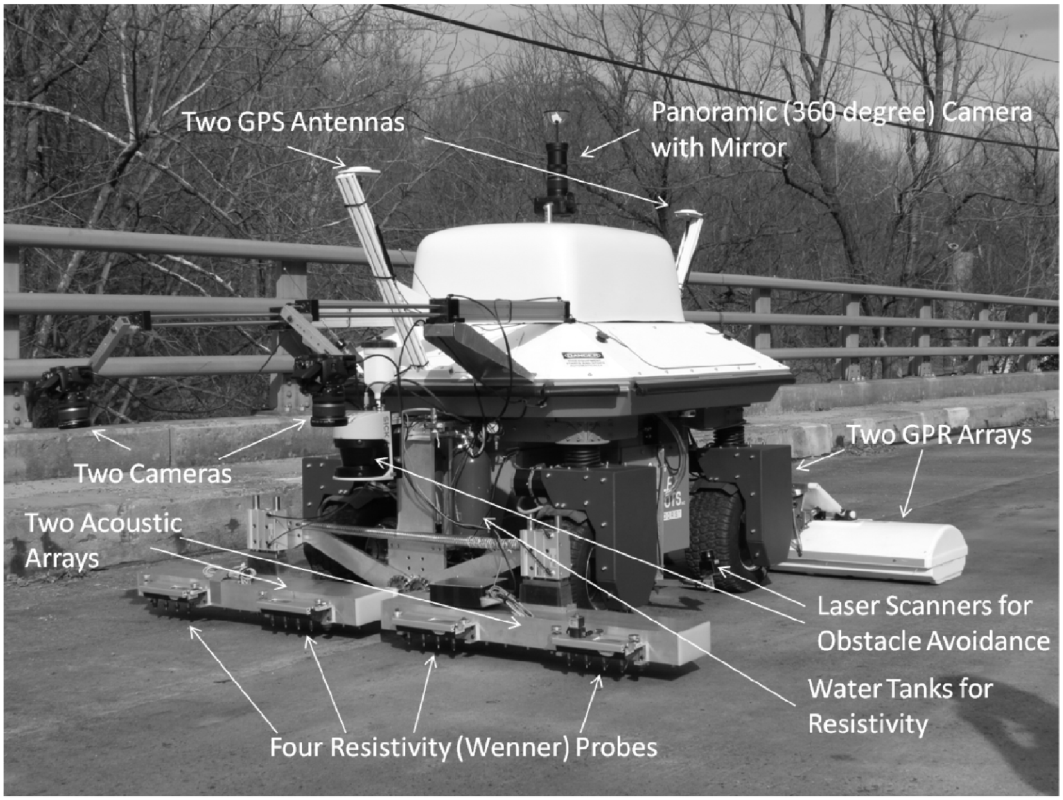

Figure 1. Components of the robotic system for condition assessment of concrete bridge decks.

Four electrical resistivity (Wenner) probes are attached on the front end of the acoustic arrays (Figures 1 and 2). The probes are used to assess the corrosive environment of a concrete deck, which in some case is well related to corrosion rates. To establish electrical contact between the concrete surface and probes, the electrodes of the four Proceq Resipod probes are continuously being moistened using a spraying system. Finally, there are three high resolution cameras (Figures 1 and 3). Two cameras on the front end of the robot are being used to capture the deck surface for mapping of cracks, spalls, previous repairs and other surface anomalies. Each of the cameras covers approximately a 60 by 90 cm area. The third camera is placed on a pneumatic mast in the middle of the robot that can lift the camera up to a 4.5 m height. The camera has a 360 degree mirror that enables panoramic images of the surrounding of the tested area.

2.2 Robotic data collection

The robotic system is able to evaluate a 1.8 m wide strip during a single pass, or half of the width of a typical driving lane. Robot path planning and its accuracy depend on three systems. As shown in Figure 1, the robotic platform carries two Novatel GPS antennas on the front and rear ends of the robot. In addition, there is a base GPS station, providing the accuracy of +/- 2 cm. The GPS systems are complemented by a wheel encoder and an inertial measurement unit (IMU). To provide the highest accuracy in the robot's movement, the three positioning systems are fused using a Kalman filter. To prepare a fully autonomous data collection, two steps are conducted. In the first step, the position of the base station is recorded. In the second step, GPS coordinates of three points on the deck are acquired. This information is sufficient for path planning. The system moves in predefined distance increments. At the end of each test line the robotic systems turns 180 degrees and continues scanning along another 1.8 m wide strip. The robot is equipped with several safety devices and measures. As illustrated in Figure 1, it has three laser scanners on the front end and sides that are used as a precautionary measure against collision with obstacles. The robot will also stop, if any of the black rubber bands on the sides of the robot are pressed, or any of the red buttons are pulled. In addition, the robotic system can be controlled by a joystick.

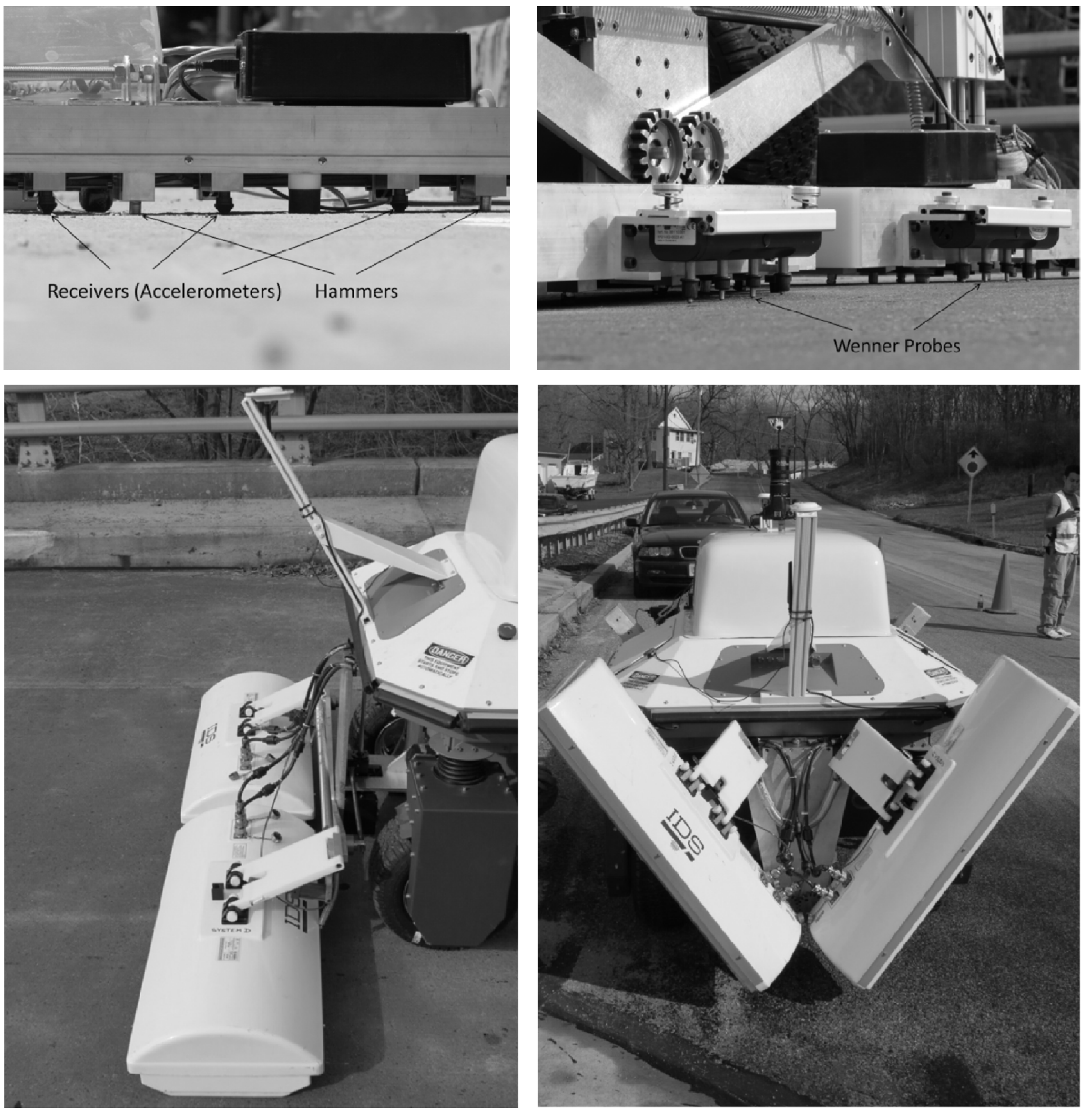

Figure 2. Acoustic array's impactors and receivers (top left), electrical resistivity probes (top right), and GPR arrays in the deployed and folded (for transportation) positions (bottom).

The robotic system is transported by a van. As illustrated in Figure 4, the robot exits and enters the van using ramps. A low power winch is assisting the robot during the loading. While transported the GPR and acoustic arrays are folded, as shown in the figure. The transporting van also serves as a command center. All the data collected by the robotic system are being wirelessly transmitted to a computer in the van for processing and display.

Figure 3. High resolution deck surface imaging camera (left) and the camera with 360 degree mirror for panoramic imaging (right).

2.3 Data analysis and presentation

The van has a command center with multiple displays. Four main displays are used for multiple functions related to: NDE data collection and imaging, data analysis, real time construction of condition and stitched deck images, crack mapping and calculation of condition indices. The complete list of display functions is shown in Table 1.

. Table 1. Display functions in the command van

GPR	USW	Impact Echo	Electrical Resistivity	Imaging (Cameras)	Other
Data collect. (B-scan)	Data collection	Data collection	Data collection	Image collection	Condition rating
Rebar picking (video)	Concrete quality map	Delamination map	Condition map (corrosive env)	Image stitching (video)	Data fusion animation
Condition map				Crack mapping	Robot position
Concrete cover				Panorama view	

For example, the operator may display, as shown in Figure 5, GPR B-scan during the data collection, rebar picking process on a previously completed GPR scan, ER data collection and generation of condition maps from selected technologies. In addition, on a pair of smaller monitors, the operator can monitor the robot movement using a van roof camera and its position on the data collection grid. Most of the condition maps are being generated as the data are being collected. The exception is GPR analysis, which is initiated once a survey line has been completed and data stored and transmitted to the command van.

Figure 4. Unloading of the robotic system from the "command van."

In addition, the interpretation and visualization platform specifically addresses data integration/ fusion of the results from the four NDE technologies and imaging. The operation of the platform is such that it facilitates intuitive presentation of the main deterioration types: corrosion, delamination, and concrete degradation. All the deterioration and defect types are presented in a common 3D space, with the ability to review the information along any horizontal or vertical surface. This data presentation is illustrated in Figure 6. Delaminations are presented as predominantly horizontal surfaces at the depth and to the horizontal extent as detected by IE test. The severity of the delamination is presented through the variation of translucency and color of the image. Similarly, the corrosive environment is displayed through coloring of rebars. Hot colors (reds and yellows) are an indication of high corrosion rates, while cool colors (blues and greens) are an indication of low corrosion rates. Zones of low modulus concrete, whether due to deterioration, segregation or other cause, primarily come from a fusion of USW and GPR data, and are described as clouds of different translucencies and color, depending on the degree of deterioration. Finally, the surface of the deck is overlaid by a high-resolution image of the deck surface with identified and marked surface cracks.

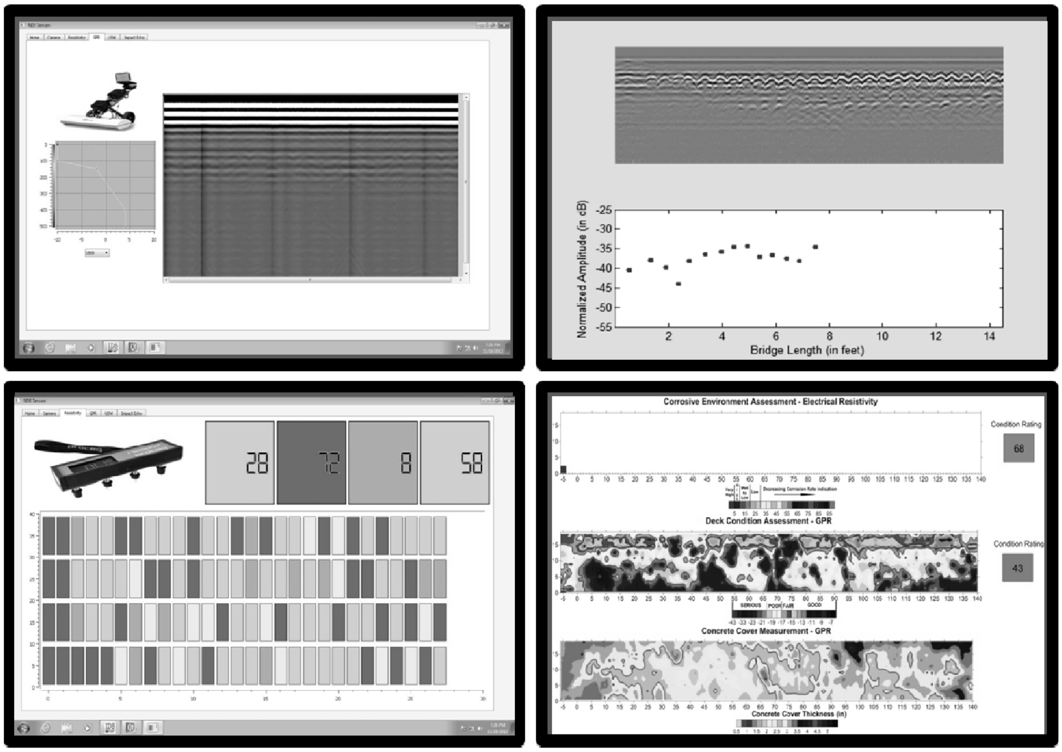

Figure 5. Data displays: GPR B-scan (top left), rebar picking (top right), ER data collection (bottom left) and condition map generation (bottom right).

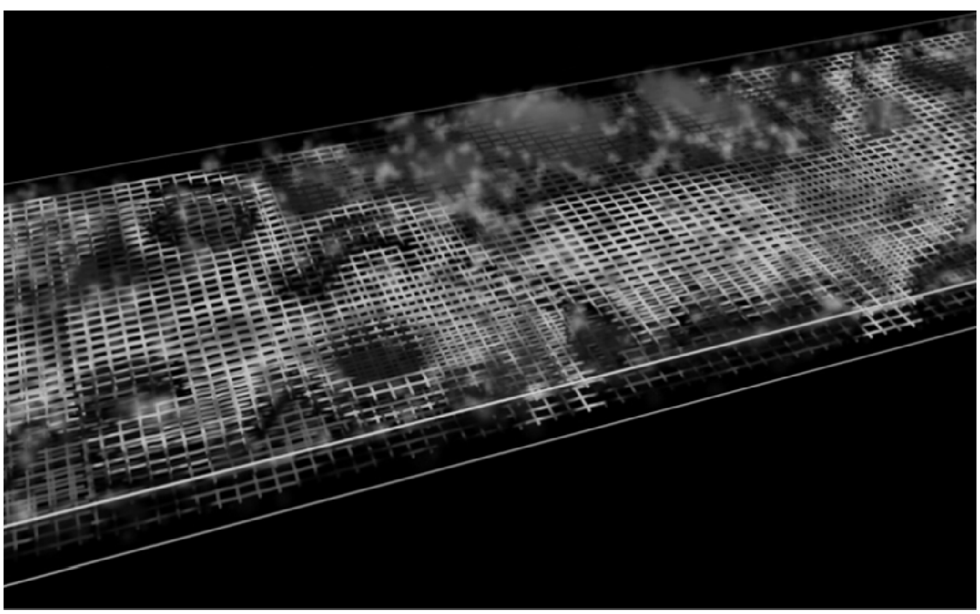

Figure 6. 3D data visualization of fused data.

3 CONCLUSIONS

The robotic system with integrated NDE technologies enables rapid and fully autonomous data collection. Complementary use of four NDE technologies: electrical resistivity (ER), impact echo (IE), ground-penetrating radar (GPR), and ultrasonic surface waves (USW), enables detection and characterization of rebar corrosion, delamination, and concrete degradation with higher spatial resolution and confidence level. The associated platform for enhanced data integration and visualization facilitates more complete review of the collected data and more intuitive presentation of the main deterioration and defect types.

4 REFERENCES

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