Concrete Bridge Deck Deterioration Detection and Characterization Using a Fully Autonomous Robotic Platform RABIT

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Abstract
Automation of nondestructive evaluation (NDE) data collection and analysis for bridge decks is a requirement for long-term monitoring of a large population of bridges. RABIT (Robotics Assisted Bridge Inspection Tool) for bridge decks provides a fully autonomous and rapid data collection using multiple NDE technologies. The system concentrates on the detection and characterization of three most common internal deterioration and damage types: rebar corrosion, delamination, and concrete degradation. For that purpose, RABIT implements four NDE technologies: electrical resistivity (ER), ground-penetrating radar (GPR), impact echo (IE) and ultrasonic surface waves (USW) method. High production rates and spatial data resolution are achieved through the use of large sensor arrays or multiple probes. RABIT surveys also complement visual inspection by collecting high resolution images of the deck surface. RABIT's components, operation, field implementation and validation are described.

Keywords: Concrete, bridge decks, deterioration, corrosion, delamination, nondestructive evaluation (NDE), robotics, automation, vision, impact echo, ground penetrating radar (GPR), electrical resistivity, surface waves

1. Introduction
Federal Highway Administration's (FHWA's) Long Term Bridge Performance (LTBP) Program has as an overarching objective to collect and manage high-quality quantitative bridge performance data for large bridge populations. Since the performance of concrete bridge decks was identified as the top priority issue, the need for a rapid and cost effective collection of bridge deck condition data became an imperative. Since bridge deck deterioration is often a set of complex processes caused by numerous physical, chemical and other factors, it requires a complementary multi-NDE technology approach to be properly characterized. The solution was sought through the development of a fully autonomous robotic system named RABIT that deploys a set of NDE technologies of that can best respond to the questions of interest. The RABIT brings together all the previous experience in manual NDE of bridge decks and use of automation in robotics, to implement it in the design, construction and operation of a robotic platform where single sensor NDT units are substituted by multiple units or sensor arrays. The platform both significantly increases the data collection speed and reduces risks related to the exposure of bridge inspectors to the passing traffic.
2. Deck Condition Assessment by RABIT

2.1 Description of RABIT robotic platform

The RABIT robotic platform with its main NDE components is shown in Figure 1. There are two acoustic arrays and four ER (Wenner) probes on the front end. Each of the acoustic arrays has seven sensors (accelerometers) and four impact sources that enable up to eight IE tests to detect and characterize delamination [1], and up to six USW tests to describe concrete quality in terms of concrete modulus [2]. The four Wenner probes enable characterization of the concrete corrosive environment and to it related anticipated corrosion rates [3]. To establish electrical contact between the probes and deck, the probes are sprayed by a spraying system. There are two GPR arrays attached to rear deployment system. Both the acoustic and GPR arrays are designed to cover a 1.8 m wide surveying strip, which corresponds to a half-width of a typical travel lane. Finally, there are three cameras, two cameras on the front end for high resolution imaging of the deck surface, and the third camera for panoramic imaging of wide bridge deck areas. RABIT collects data fully autonomously where navigation depends on three systems: a differential GPS, distance measurement unit and inertial measurement unit. High mobility of the platform is provided by its omni-directional wheels. The RABIT can be programmed to collect data at any increments. For a most commonly used 0.6 m increment, the RABIT can collect data at rates of about 350 to 400 m²/hr. The data being collected are streamed wirelessly to the "command van" where they are being displayed and in the greatest part analyzed and presented in near real-time. The van is used to transport the RABIT, for which the sensor arrays are folded.

Figure 1. RABIT during data collection and its components.
2.2 Typical RABIT survey results

The results of a RABIT surveys are typically presented in terms of condition maps, as illustrated in Figure 2 for a bridge over Pohatcong Creek near Bloomsbury Township, New Jersey. The bridge was surveyed in May of 2015. The first observation is that there is a significant similarity between the ER and GPR in terms of the zones of low resistivity and high attenuation, respectively. This confirms strong influence of electrical conductivity of concrete on both measurements. The second observation is the similarity of identified delaminated areas in the IE map, and low modulus areas in the USW, with the "problem" zones in ER and GPR maps. This leads to a conclusion that the primary driver of deterioration is corrosion. The maps from the RABIT survey are in high agreement with the condition maps, not shown herein, from a survey conducted in August of 2014. To provide summary grades with respect to corrosion, delamination and concrete quality, summary grades are provided in terms of condition indices. Condition indices are weighted averages of percentages receiving different condition grades on a scale 0 to 100. For example, the Pohatcong Creek bridge received 32.2 delamination index from IE, and only 1.4 corrosion index from ER.

Another important result is a high resolution stitched image of the deck surface. Such an image can be used for crack mapping and marking of all visible damage and previous repairs. It is a permanent record of visible damage that can be compared to the damage observed during the next inspection. Another important element in the RABIT "toolbox" is a 3D visualization platform that enables integration and visualization of the NDE results and images in a very intuitive way. The main deterioration types: corrosion, delamination, and concrete degradation (low quality concrete), and the deck surface defects are presented in a common 3D space, while the surface of this 3D deck volume is overlaid by a high-resolution image of the deck surface.

3. Conclusions

RABIT's fully autonomous and automated multi NDE data collection opens an opportunity for comprehensive condition assessment and long term monitoring of large bridge populations. It will significantly reduce the required workforce and exposure of the bridge inspection crews. Complemented by an advanced data fusion and visualization, RABIT's results will also enable problem detection with higher confidence.

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References

Figure 2. Condition maps for Pohatcong Creek Bridge deck from ER, GPR, IE and USW (from top to bottom).