DRISI

Caltrans Division of Research, Innovation and System Information

Research Results

Research to Integrate Color and Thermal Imaging IR cameras with Caltrans 3D-GPR and GNSS/INS System.

Integrating 3D-GPR, color and infrared cameras, and GNSS/INS to enable the detection of roadway substructure faults at highway speeds.

Geotechnical/ Structures

MARCH 2021

Project Title:
Integrating Color and Thermal Imaging IR cameras with Caltrans 3D-GPR and GNSS/INS System

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WHAT WAS THE NEED?

The California Department of Transportation (Caltrans) Geophysics and Geology Branch needed a safer, more effective, high-speed and efficient way to collect three-dimensional ground penetrating radar (3D-GPR) and thermal infrared (IR) image data as well as color images for visual references. For imaging of bridge decks and tunnel linings under Strategic Highway Research Program (SHRP2) Products R06A and R06G, and for support of Structures Maintenance, polarized visual and thermal IR imaging would revolutionize effectiveness of the technology and significantly reduce acquisition costs.

The Caltrans 3D-GPR and IR imaging collection vehicle needed to be able to collect IR images, polarized visual images, and 3D-GPR data in a single pass at highway speed, with operators inside the protection of the vehicle without direct exposure to highway traffic.

Various investigations have been conducted on Nondestructive Evaluation (NDE) methods for concrete and pavement subsurface damage and deterioration. 3D-GPR and Thermal IR imaging NDE technologies provide the means for rapid, nondestructive, and accurate condition assessment and performance monitoring of concrete bridge decks, pavements, and tunnel linings. Both NDE methods have the potential to significantly reduce resources and expenditures required for renewal and repair. Aside from reducing the duration of traffic interruption during field operation, the denser measurements yield a more accurate characterization of the concrete and pavement subsurface condition, a better prediction of the deterioration progression, and a better assessment of the rehabilitation needs.

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3D-GPR and IR imaging ranked high in the SHRP2 NDE evaluations. They have been applied separately by several agencies as tools for concrete surface condition assessment. However, there is limited reported work describing the combined use of the results of these two methods. 3D-GPR and thermal IR imaging each have their limitations but they also have complementary strengths. GPR is equally effective on bare concrete decks and on decks with concrete and bituminous overlays. Thermal IR imaging is effective for imaging the debonding of concrete decks and overlays but may have limitations detecting rebar-level delamination if the rebar is deep. While it is very effective for non-overlaid decks, thermal IR's effectiveness can be reduced in the presence of overlays. In previous studies, users were on foot using a hand-held thermal IR imaging camera and could not capture inside lanes without a lane closure.

WHAT WAS OUR GOAL?

Our goal was to investigate an optimal method to configure and integrate color and thermal imaging IR cameras with Caltrans 3D- GPR and Global Navigation Satellite System/Inertial Navigation System (GNSS/INS). The integrated system would be mounted on a Caltrans van to detect roadway substructure faults at highway speeds and placed into service for statewide testing and monitoring of California's highways, bridges, and tunnels. The ultimate goal of the project was to provide a means to improve monitoring of California's infrastructure health (at highway speeds), which will both a) reduce impacts to the traveling public and b) significantly improve operator safety.

WHAT DID WE DO?

The research explored literature and industry publications, identified and then evaluated innovative IR and polarized visual cameras, selected the best candidates, and integrated them with the existing Caltrans 3D-GPR vehicle.

The researchers developed the equipment designs, integration architecture, and established the operating procedures and processing methods for the integrated GPR, color camera, thermal IR camera, and the polarized visual analysis. The researchers successfully created an integrated system incorporating commercially available and customizable equipment into the existing Caltrans GPR and GNSS/INS subsystems and equipment. The final system has incorporated all needed features that the researchers had identified in cooperation with Caltrans Geophysics and Geology Branch.

Working with Caltrans staff, the researchers retrofitted the Caltrans van with the integrated system and its cameras. The integrated vehicle was field-tested by Caltrans using a 2-person crew (including the van driver). All integrated units (subsystems) worked together in an integrated fashion as designed.

WHAT WAS THE OUTCOME?

The project's outcome was an improved and safer hardware-software system that Caltrans can use to inspect roadway integrity and identify pavement and roadway substructure faults and defects. The new system consists of integrated color and thermal imaging IR cameras working in sync with Caltrans 3D-GPR and GNSS/INS System. In addition, if needed, the system can be replicated and additional Caltrans vehicles can be retrofitted and put into service.

WHAT IS THE BENEFIT?

This research has, and will continue to yield multiple benefits to Caltrans as well as the traveling public and taxpayers in the State of California. The newly configured system and method of operation improves the quality of the operational assessment of conditions of pavement and roadway substructure concrete surfaces. The comprehensive and accurate assessments provided by the system are expected to substantially reduce the cost and frequency of detailed regular and follow-up inspections.

In addition, data collected from the nondestructive testing (NDT) of pavement and concrete surfaces should complement other information in order to better understand life-cycle costs, deterioration mechanisms, and the effectiveness of preservation techniques at various stages of the aging process. It will lead to early detection of defects, lower rehabilitation costs, and higher levels of service.

Most importantly, the system investigated and configured in this research and the resulting method of operation will reduce the need for lane closures while increasing data acquisition speed. This will bring additional benefits in terms of decreased disruption to traffic as well as improved safety for maintenance workers, equipment operators, system testers, system investigators, and the traveling public.

Finally, through the current SHRP2 grants, Caltrans Geophysics and Geology Branch have actively engaged, and will continue to engage, with other Departments of Transportation (DOTs) and researchers to share the results of this research and contemplate future enhancements. The Federal Highway Administration (FHWA) and other DOTs are interested in the results of this leading research and will benefit from its applications at other states and highways nationwide. The research enhances Caltrans excellence and national leadership and contributes to achieving Caltrans Strategic Goals of improving safety, system performance, efficiency, and the state's economy.

LEARN MORE

To view the final report, contact Dr. Mohamed Alkadri at mohamed.alkadri@dot.ca.gov.

IMAGES

Figure 1: A frontal view of Caltrans' 3D Radar vehicle. The 3D-GPR antenna array (with a yellow top) is mounted on two racks at the front of the vehicle.

Figure 2: The driver's guidance display. It guides the driver to the proper location within the lane for complete and accurate data collection.

Figure 3: A rear view of Caltrans' 3D Radar vehicle. The dual GNSS antennas that provide accurate positioning are mounted near the center of the roof of the vehicle (a). Above the rear doors are the B/W camera (enclosed inside a stainless steel waterproof housing) and the FLIR IR Camera, both pointing towards the pavement (b). Mounted on the left rear wheel is the Distance Measurement Unit (DMI), which is connected to the Applanix GNSS/IMU system and GeoScope (c).

The GPR and its antenna (figure 1) and the unites shown above operate as an integrated system allowing multiple streams of digital and video data to be collected at highway speeds, without the need for closing lanes.

Figure 4: A lockable storage system mounted at the rear of the 3D vehicle. It provides secure storage and transportation for the 3D GPR antennas and sensor mount.

- The top drawer stores the ground couple 3D GPR antenna with tools and accessories.
- The lower left drawer stores the air couple GPR antenna.
- The lower right drawers stores the air couple GPR antenna mounts.

Image 5: A sample graphic of the Pavement Intralayer GPR Response. Intralayer GPR Response provides an indicator for overlay stripping or delamination.

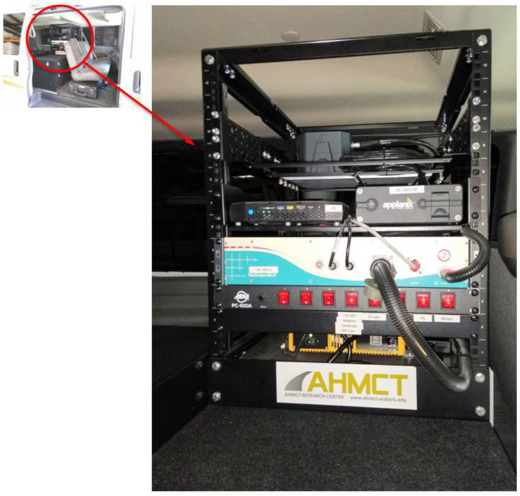

Figure 6: The equipment rack enclosure provides secure mounting of various 3D GPR electronic components including:

- Inverter (located at the bottom),
- GeoScope MK IV computer for 3D GPR data acquisition,
- Operator interface computer (labeled PC),
- Applanix GNSS/IMU computing system,
- The IMU (located on the very top)
- The power supplies (located behind the GeoScope).

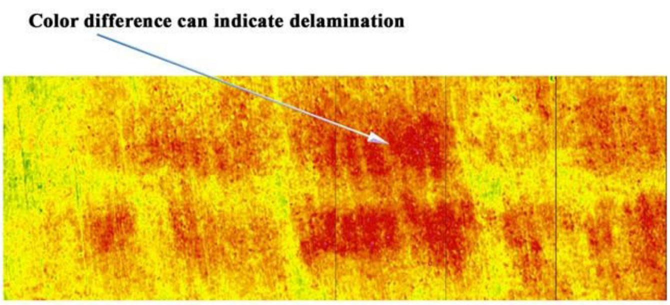

Image 7: A sample of a processed thermal image of a bridge deck where the color difference (red shade) can indicate delamination.

Source: FHWA NDE Web Manual, at: https://fhwaapps.fhwa.dot.gov/ndep/DisplayTechnology.aspx?tech_id=14

Figure 8: The 3D GPR operator's user interface. The interface enables the operator to monitor the proper functioning of sensors, cameras, and data collection.

The display shows the thermo-imaging from the FLIR IR camera (right screen) and pavement images from the B/W camera (left screen).