PI-0384 - Assessing the Deployment Potential for Thermal Infrared Technology for Inspection of Pavement and Concrete Bridge Decks in California

Requested by
Chris Traina, PE, Supervising Bridge Engineer, DES

Prepared by
Payman Hajiani, Ph.D., PGP, Engineering Geologist, DES
Bill Owen, PG, CEG, PGP, Senior Engineering Geologist, DES
David Liao, PE, Senior Research Engineer, DRISI
Seung Han Kim, Ph.D., PE, GE, Senior Bridge Engineer, DES

in collaboration with

Kin Yen, Senior Development Engineer, AHMCT, UC Davis
Iman Soltani, Ph.D., Assistant Professor, UC Davis

May 14, 2025

Table of Contents

Executive Summary

The Strategic Highway Research Program recognized the utility of Thermal Infrared (IR) for early identification of shallow-seated deterioration in pavements and bridge decks. Early detection allows repair and rehabilitation ahead of significant degradation, saving time and money on maintenance. Extensive research, performed by numerous researchers, on using IR thermography to detect pavement debonding and delamination in laboratory setup has shown positive results. There were few pilot studies to apply laboratory findings to real world data. Researchers have encountered challenges in applying IR thermography in the field deployments. Data, results, and lessons learned from field deployments were limited.

Through previous Caltrans DRISI research projects, a readily deployable Caltrans NDE van was developed. The Caltrans NDE van system enables georeferenced B/W and thermal IR imaging of pavement and deck surfaces concurrent with 3D Ground Penetrating Radar (GPR) imaging of the subsurface. This integrated vehicle sensing platform can collect data while the vehicle is moving at highway speeds, eliminating the need to close lanes or slow traffic.

More pilot projects are needed to significantly improve Caltrans' field experience in inspecting pavement and bridge decks using IR thermography. Caltrans Geophysics and Geology Branch has developed a research plan to gain field experience and develop standard workflow to overcome challenges identified by other researchers.

Detailed Findings

Background

Caltrans must inspect pavement and bridge decks to support proactive infrastructure maintenance. Caltrans needs to leverage emerging non-destructive evaluation (NDE) technologies for sensing and data processing to best perform this critical duty.

The Strategic Highway Research Program recognized the utility of Thermal IR for early identification of shallow-seated deterioration in pavements and bridge decks [1]. Early detection allows repair and rehabilitation ahead of significant degradation, saving time and money on maintenance. Caltrans has installed a thermal IR system on its 3D Ground Penetrating Radar (GPR) vehicle, allowing georeferenced visual and thermal IR imaging of pavement and deck surfaces concurrent with 3D GPR imaging of the subsurface. Implementation began through DRISI's Advanced Research Program, Task 3608 and Task 3924. Task 3608 performed literature reviews and established system requirements for the Infrared camera [2]. Task 3924 overcame some significant technical hurdles and produced a deployment-ready system for acquisition of accurately ortho corrected and georeferenced thermal IR and visual imagery [3]. Further research is required to develop standard operating procedures (SOPs), establish best practice recommendations, and integrate the technology into Caltrans' existing inspection framework.

Figure 1: The Caltrans NDE vehicle. In project deployment, either the front or rear GPR antenna is used. The IR and B/W housing is mounted at the NDE vehicle rear on top of the roof

Summary of Related Research and Resources

Researchers, the Federal Highway Administration (FHWA), and the Transportation Research Board (TRB) have performed various investigations on Nondestructive Evaluation (NDE) methods for concrete and pavement subsurface damage and deterioration [4-10]. Ground Penetrating Radar (3D-GPR, also GPR) and thermal Infrared (IR) imaging NDE technologies provide the means for rapid, nondestructive, and accurate condition assessment and performance monitoring of concrete bridge decks and pavement. Both NDE methods will significantly reduce the resources and expenditures needed for testing, renewal, and repair. Aside from reducing the traffic interruptions during field operation, the high-resolution 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.

There has been extensive research on the use of IR thermography for bridge and pavement distress detection [6]–[36]. Previous research typically used handheld thermal imaging equipment. Hiasa and Matsumoto [6], [17] – [19], [37], [38] have performed extensive research on using thermal IR imaging cameras in mobile high-speed applications instead of a handheld thermal IR imaging camera on a tripod. Their findings show that there are four key specifications for an IR camera to be used in detecting pavement and bridge deck distress: image resolution, temperature sensitivity, sensor integration time, and frame rate. Other important specifications include inter-changeable lenses and external image trigger support for geo-referencing of the data.

Literature reviews were conducted to identify available software for IR camera image and georeferencing data collection and IR image post-processing for delamination detection. FLIR's ResearchIR software was provided by FLIR when purchasing the IR camera. ResearchIR software allows users to collect data from a FLIR IR camera and provides basic image and IR data analysis tools. Literature review further revealed that there is a MATLAB library for reading the FLIR raw files collected and stored by the ResearchIR software. We also found non-destructive testing (NDT) service providers who had developed their own in-house IR camera data collection and post-processing software. However, their software is not available for sale. Examples of such NDT service providers are:

- Penetradar.com (http://www.penetradar.com/infrared-thermography-(irt)-inspection-of-bridge-decks.html)
- Infrasense.com (https://infrasense.com/technology/infrared-thermography)
- Infrared-diagnostics Inc (https://www.infrared-diagnostics-inc.com/bridge-deck-investigation)

In collaboration with the Nebraska Department of Transportation (DOT), University of Nebraska researchers utilized FLIR's ResearchIR software and MATLAB to post-process temperature data stored in the FLIR-TIFF file format from ResearchIR. [39, 40]. Shen et al. developed three different methods: a grayscale morphological reconstruction method, level-set segmentation method, and deep learning method to determine delamination and debonding defect locations [39]. They found that the level-set method has an average 80.2% correct prediction rate (CPR), and the deep learning method achieved 78% CPR. They also found that the σ (standard deviation) CPR of the deep learning method is slightly greater than the level-set method, which indicated that performance of the deep learning method was less consistent (larger variance) than the level-set method. Their research also identified challenges and pitfalls of using IR data. These challenges are:

1) Shadows from trees, bridge parapet walls, light poles, etc.

2) Dark asphalt smears on concrete decks.

3) Excessive dirt/gravel coverings on the deck surface.

4) Patches of significantly different materials/colors and textures.

5) Wet deck surfaces or even dry surfaces shortly after rains.

Shen et al. suggested that users' discretion and experience are needed to mitigate these real-world field survey conditions. Chen et al., at University of Nebraska-Lincoln, applied Convolutional Neural Network (CNN) and Dense Convolutional Network (DenseNet) to detect delamination from data collected under different conditions in the laboratory [41] and showed promising results. Aljagoub et al., from the same research group at the University of Nebraska-Lincoln, have used uncooled UAV infrared camera in collecting IR data and detecting concrete delamination [42, 43].

In previous Caltrans DRISI research Task 3924, Caltrans Geophysics and Geology Branch deployed the developed Caltrans NDE on limited pilot projects. Figure 2 shows a sample overlay of the pavement intralayer GPR response on a road segment, which highlights localized signs of overlay stripping or delamination.

Figure 2: A sample graphic of the pavement intralayer GPR response, which provides an indicator for overlay stripping or delamination. Image courtesy of Google Earth.

Figure 3 (image on the left) shows a thermal image of a test sample pavement featuring two known defects collected by the Caltrans NDE van at the State Transportation Laboratory in Sacramento. Figure 3 (image on the left) provides a false color image, representing different temperatures at the pavement surface. The two rectangular shapes, displaying comparatively large change in temperature, on the left side of the image highlight two areas with known defects and delamination. The black and white image on the right in Figure 3 shows an image of the same area captured using a black and white camera.

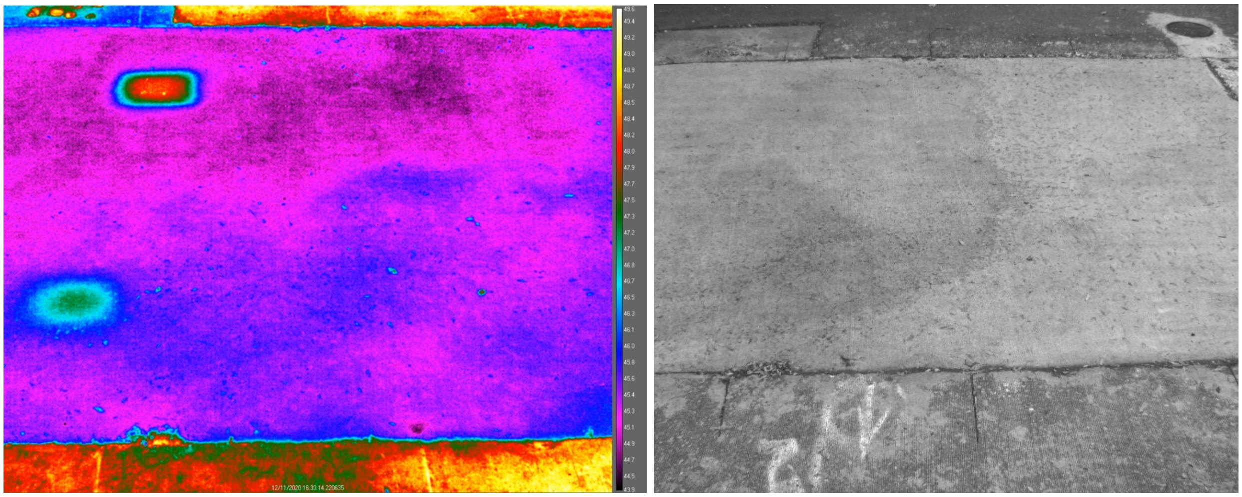

Figure 3: A sample thermal image of a test pavement at State Transportation Laboratory with two known defects (image on the left). The image on the right shows a black and white image of the same area of the test pavement.

Task 3924 evaluated availability of commercial off-the-shelf software (COTS) for thermal IR data acquisition and processing. Results identified availability of an application developed by NEXCO-West USA (IrSUITE). Evaluation of that COTS application concluded that IrSUITE is suitable for the intended applications required under Task 3924. The software was acquired under this Task, and NEXCO-West provided initial user training at the AHMCT facility. An example of the processed data acquired during the training is shown in Figure 4.

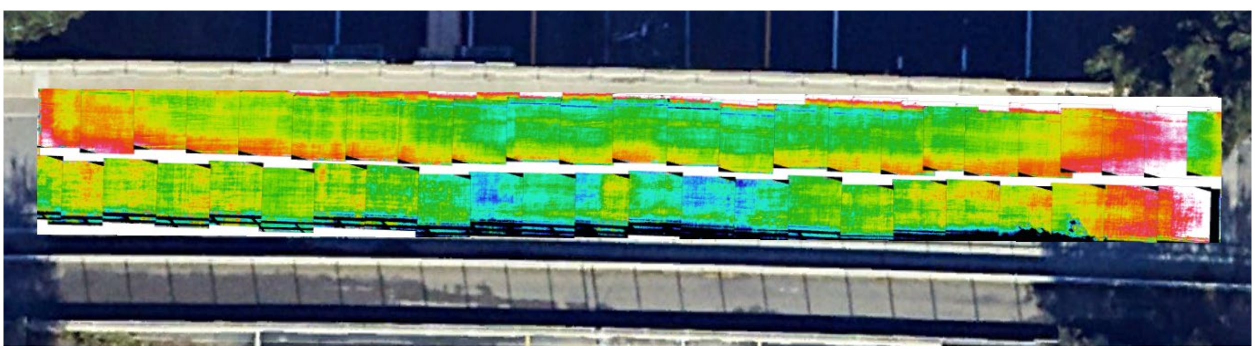

Figure 4: Thermal image of a concrete bridge deck over State Route 113, acquired and processed using IrSUITE. Image produced from Google Earth KMZ overlay.

Gaps in Findings

Extensive research on using IR thermography to detect pavement debonding and delamination in laboratory setup has shown positive results. There were few pilot studies to apply laboratory findings to real world data. Researchers have encountered challenges in applying IR thermography in the field. There are service providers that perform IR thermography for pavement distress detection. However, their workflow and standard operating procedures are not shared nor are their collected data available for training. Authors did not find any field IR thermography data of distressed pavement. The lack of published workflow and standard operating procedures to mitigate field challenges hinders large scale deployment of the IR thermography technology for pavement distress detection.

In addition, the lack of real world field IR thermography data of distressed pavement poses difficulties in training staff in post-processing IR thermography to identify area of distressed pavement. Furthermore, real world data are vital in subsequent research phases for applying machine learning technology to automate pavement distress identification.

Next Steps

In a previous Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center project performed under the Second Strategic Highway Research Program (SHRP2), a readily deployable Caltrans NDE van was developed. The Caltrans NDE van system enables georeferenced B/W and thermal IR imaging of pavement and deck surfaces concurrent with 3D GPR imaging of the subsurface. This integrated vehicle sensing platform can collect data while the vehicle is moving at highway speeds, eliminating the need to close lanes or slow traffic. The NDE van is operational for GPR investigations and is successfully performing GPR inspections for pavement and bridge decks throughout the state.

More pilot projects are needed to significantly improve Caltrans' field experience in inspecting pavement and bridge decks using IR thermography. Through pilot projects, users and researchers will:

- Gain experience to develop best practices, workflows, and standard operating procedures for collecting IR thermography pavement data in the field to produce consistent high-quality data.
- Gain experience to determine best practices for identifying distressed pavement.
- Collect field IR thermography pavement data for personnel training in interpretation and presentation of results.
- Provide real-world data for automation development in subsequent phases.

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