Roadway Ice/Snow Detection Using a Novel Infrared Thermography Technology

tech transfer summary

working to advance road weather information systems technology

Automated evaluation of roadway snow coverage can facilitate local agency decision-making and performance evaluation during winter storms while enhancing roadway safety.

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RESEARCH PROJECT TITLE
Roadway Ice/Snow Detection Using a Novel Infrared Thermography Technology

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The Aurora program is a partnership of highway agencies that collaborate on research, development, and deployment of road weather information to improve the efficiency, safety, and reliability of surface transportation. The program is administered by the Center for Weather Impacts on Mobility and Safety (CWIMS), which is housed under the Institute for Transportation at Iowa State University. The mission of Aurora and its members is to seek to implement advanced road weather information systems (RWIS) that fully integrate state-of-the-art roadway and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures.

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Background

About 70% of road networks in the United States experience slippery conditions during the winter season, which can significantly reduce tire friction and lengthen vehicle braking distances, increasing the risk of vehicle crashes.

Agencies find it critical to clear road surfaces in time to ensure traffic safety during ice and snow seasons. Consequently, winter traffic safety management is viewed as the top priority of many state departments of transportation (DOTs) in snowy regions.

While methods for assessing winter road conditions have been developed, previous work has not focused on the simultaneous use of optical and infrared images to detect slippery roadway conditions under varying illumination conditions.

Problem Statement

Development of technology that can assess slippery road conditions for real-time traffic safety evaluations is highly desirable. However, accurate and full-scale detection of ice and snow patterns on the pavement has been difficult to achieve.

Project Goals and Objectives

This project aimed to develop a convenient tool capable of evaluating slippery road conditions over multiple lanes during winter seasons. Specific objectives included the following:

- Evaluate the feasibility and effectiveness of using dual-spectrum (optical and infrared) imagery for estimating roadway snow coverage using optical and infrared images in sufficient and poor illumination conditions
- Develop computer vision and machine learning approaches to evaluate road surface conditions based on dual-spectrum imagery
- Develop a transfer learning technique to evaluate road surface conditions based on a limited dataset of dual-spectrum imagery

Research Description/Summary

Roadway images were collected over two winter seasons at two sites in Utah using a different dual-spectrum network camera at each site. At both sites, the camera was set at a fixed position to allow the optical and infrared lenses to cover five and three lanes, respectively.

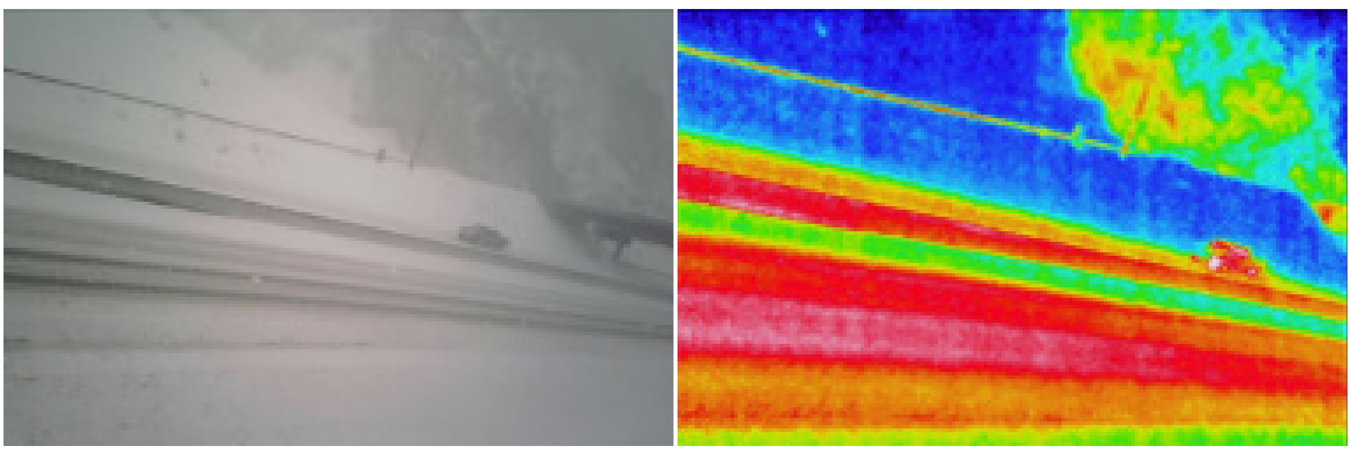
Camera installation at a field test site

Image registration was first performed to align the infrared and optical images for computational convenience. A lane splitting process based on segmentation and morphological operations was then performed on images without snow or vehicles to determine lane boundaries. Images were then labeled to establish the ground truth for subsequent analyses.

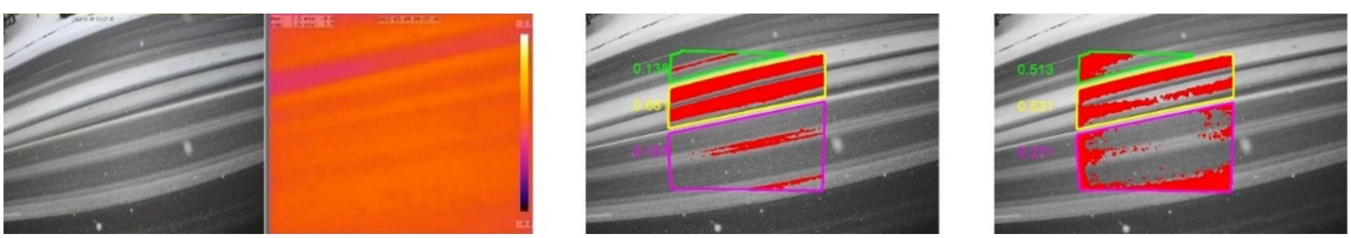
Based on the pre-processed images, a computer vision framework was developed to estimate snow coverage on the lanes. Two-dimensional (2D) fast Fourier transform (FFT) was used to extract feature vectors from the images, and image segmentation was performed using unsupervised k-means clustering and a supervised support vector machine (SVM) method.

The snow coverage ratio of each lane was estimated using optical images during the daytime and infrared images at night. Performance was evaluated via confusion matrices based on the established ground truth.

To account for the relatively limited data volume, snow coverage was also estimated using a transfer learning framework based on the U-Net architecture implemented in the Keras framework. This approach eliminated the need to train a large number of hyperparameters.



Daytime dual-spectrum imagery collected during a winter storm



Snow coverage detection in daytime images: original optical and infrared images (left) and segmentation based on optical (middle) and infrared (right) images

Key Findings

- The developed data acquisition system and its optical and infrared images were successfully used for snow detection and roadway snow coverage estimation.
- Optical images can detect snow detection in sufficient illumination conditions, though their performance degrades significantly at night or during snowstorms. Infrared images outperform optical images when illumination is low and temperature contrast is high but do not perform well if the roadway surface reaches thermal equilibrium.
- Since the developed computer vision method relies on textures in optical and infrared images, its performance is governed by contrasts provided by pixel intensity or temperature.
- Image segmentation using k-means clustering performed similarly to image segmentation using SVM.
- The transfer learning model can be particularly advantageous in scenarios where the acquisition of a substantial amount of labeled data presents challenges or requires a significant investment of time.
- The transfer learning algorithm achieved a precision of 88% using daytime optical images and an impressive precision of 94% when using nighttime thermal images despite the constraints imposed by the limited dataset.
- The U-Net transfer learning model generally demonstrated superior or similar performance and efficacy when compared to k-means clustering and SVM.

Implementation Readiness and Benefits

The methodology developed in this study for detecting slippery road conditions was able to assess snow coverage across multiple lanes at a high rate of accuracy and precision with a relatively small dataset.

The methodology offers the potential to facilitate local agency decision-making in winter maintenance planning and performance evaluation and to enhance winter roadway safety. The equipment, workflow, and architecture used in this study are described in the final report for this project.

Limitations and Recommendations for Future Development

- The developed methodology was not tested for roadway ice detection because the ground truth was not available from optical images, which do not reliably indicate roadway ice. Data collection at test sites with different roadway conditions is recommended.
- Direct sunlight may influence the performance of infrared cameras in the daytime. The effects of direct sunlight on infrared camera lenses should be further investigated.
- While labeling optical and infrared images is critical to algorithm development, manual labeling is time-consuming and prone to errors. An efficient image labeling procedure should be considered for future studies.
- To facilitate implementation, the technology assessed in this research should be based on dual-spectrum or infrared cameras that are compatible with local fiber optic systems. Integrating the methods developed in this research into a state DOT's existing road monitoring systems could otherwise prove challenging.