working to advance road weather information systems technology

Optimal RWIS Sensor Density and Location – Phase IV

tech transfer summary

Automating the estimation of winter road surface conditions has the potential to improve the speed, efficiency, and cost-effectiveness of winter road maintenance activities.

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RESEARCH PROJECT TITLE
Optimal RWIS Sensor Density and Location – Phase IV

SPONSOR
Federal Highway Administration Aurora Program Transportation Pooled Fund (TPF-5(435); Aurora Project 2021-05)

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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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Objectives

- Further develop techniques for automating the estimation of winter road surface conditions (RSC), including convolutional neural networks (CNN), explainable artificial intelligence (XAI), deep learning (DL)-based computer vision, regression kriging (RK), and nested indicator kriging (NIK)
- Provide winter maintenance personnel with analytical tools, such as a web application, to help them better utilize the resources at their disposal for effective winter road maintenance (WRM)

Background and Problem Statement

Monitoring RSC during the winter season is important for transportation agencies performing WRM activities. To conduct these activities efficiently, it is crucial that state transportation agencies have up-to-date information on road conditions.

To accomplish this, road weather information systems (RWIS) are used to gather and transmit data, which assists road maintenance personnel in effectively planning WRM activities. However, the RSC of the road segments in the images obtained by stationary RWIS are still evaluated manually, which prevents the full utilization of this data. The limited number of stationary RWIS stations also results in significant spatial gaps along the highway network.

Typical stationary RWIS station

Mobile RWIS unit equipped with spectral road surface temperature sensor

In previous studies, the researchers developed techniques based on two fairly common RSC modeling techniques, CNN and RK. These methods had some limitations, including the ability to recognize stationary RWIS imagery, convert to numerical performance/RSC indices, estimate categorical RSC variables, and characterize weather events.

Research Description

Building on the previously developed modeling techniques, this project introduced a CNN model specifically designed for stationary RWIS imagery. To validate the accuracy and reliability of the CNN's predications, two XAI techniques were used: SHapley Additive exPlanations (SHAP) and class activation map (CAM)-based methods. These techniques reveal the internal workings of CNN models by identifying the areas that are most influential in the model's predictions.

To convert stationary RWIS imagery into a numerical index of pavement snow status, two distinct deep learning models were developed and implemented: pix2pix generative adversarial network (pix2pix GAN) and semantic segmentation (SS).

To enhance the previously developed RK method's ability to spatially map continuous RSC across unmonitored areas, a machine learning (ML)-based clustering method using the K-means algorithm was introduced. Subsequently, the RK method, including multiple linear regression (MLR) and semivariogram models, was applied to automatically map RSC spatially between RWIS stations.

To address the limitations of RK in handling categorical variables, a novel geostatistical method (NIK) was developed to directly estimate categorical RSC for all unmonitored areas with the input of CNN classification results.

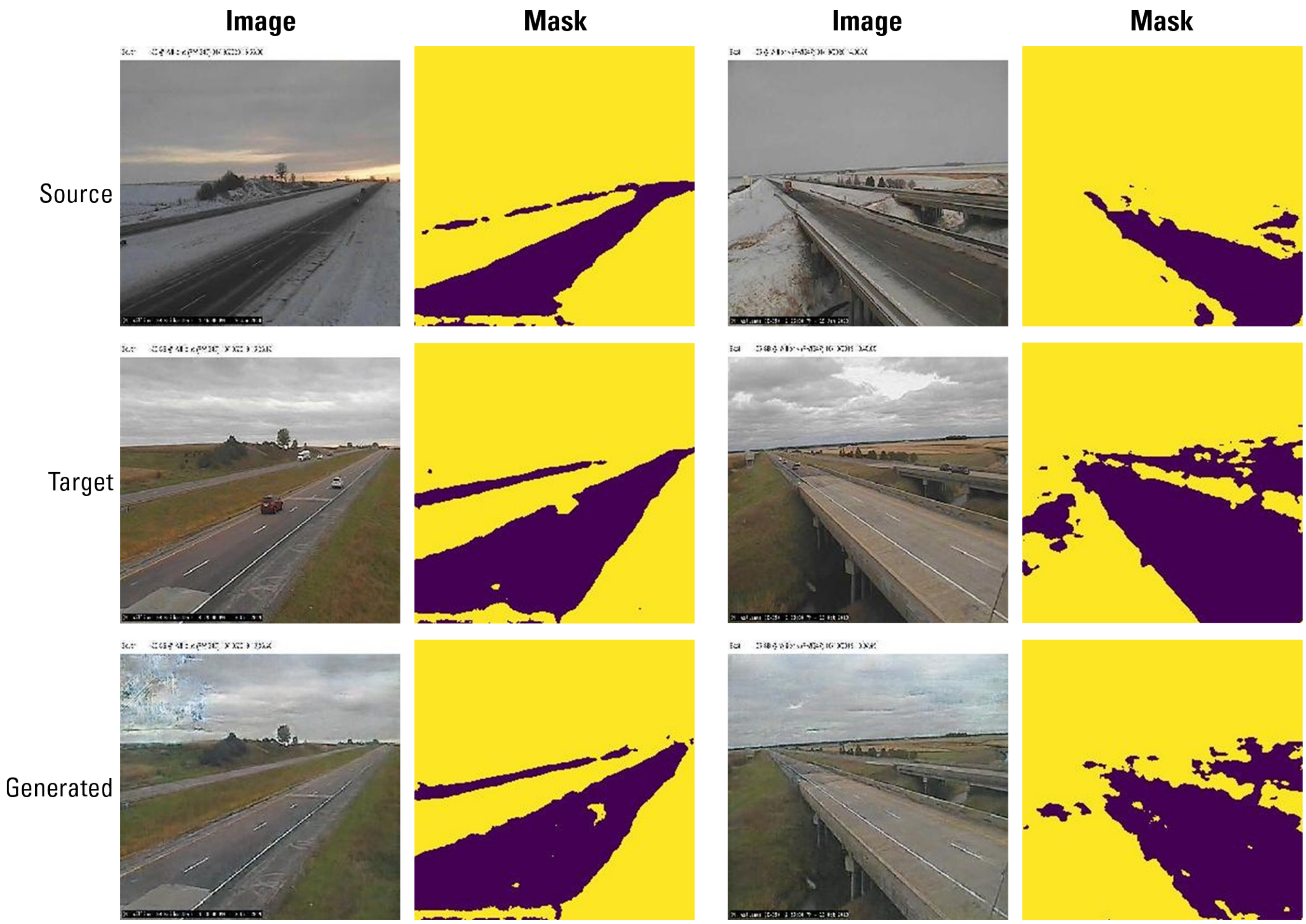
Finally, the potential benefits of having spatially rich RSC information using this refined method were analyzed.

These methods were evaluated using data from two major highways, I-35 and I-80 in Iowa, spanning a five-year period and encompassing over 20,000 images. A web application integrating the relevant developed models was created, serving as a comprehensive platform designed to empower WRM decision-makers with real-time RSC monitoring capabilities.

Key Findings

- CNNs are an effective way to classify mobile RSC images and stationary RSC images.
- In differentiating the snow hazard levels at RWIS sites through imagery analysis, both DL-based computer vision techniques, pix2pix GAN and SS, performed their tasks with a high degree of accuracy, providing reliable estimations of snow coverage ratios (SCR).
- The newly-developed NIK method showed promising results based on the limited data collected.
- The refined RK method, which incorporated the K-means algorithm, maximizes the use of data from existing RWIS stations to bridge their large spatial gaps, providing a more comprehensive picture of RSC across the highway network.
- A web application based on these techniques was developed and is available at **https://vstfl.github.io/mapbox-rsi/**.
- In quantifying the potential savings derived from optimally placed RWIS stations and reduced traffic collisions, it was found that 10 RWIS stations could be conserved, translating into substantial monetary savings in RWIS capital costs, enhanced traffic mobility, and reduced maintenance material usage.

Examples of stationary RWIS images



Example outputs of approach for estimating snow coverage area

Recommendations and Future Development

- Provide additional training for stationary RSC images in situations where variations in camera angle or the presence of complex structures in the image exist, as these factors can influence model performance.
- Include a broader range of images in the model training process for both pix2pixGAN and SS models to enhance the generalization of SCR estimation for RWIS imagery.
- Conduct spatial and temporal interpolation of these determined RSC measurements for locations without RWIS stations or roadside cameras.
- Explore additional RSC variables when data become available. Expanding the scope of investigation to larger highway networks, different states and provinces, and a broader range of weather events will help verify and generalize the results obtained in this project.
- Optimize RWIS station configuration and density, ensuring accurate RSC estimations and efficient resource allocation.

Implementation Readiness and Benefits

The variety of techniques presented here represent a significant advancement in RSC monitoring and estimation and can ultimately promote a safer, more mobile, and sustainable winter transportation system.

Overall, the techniques evaluated were found to be feasible, but further research is needed to fine-tune their architectures, hyperparameters, and other settings to improve performance.

The web application developed during the course of this study offers real-time monitoring, estimation, and historical data archiving to decision-makers, equipping them with a powerful tool to implement WRM activities more swiftly, efficiently, and cost-effectively.