Deep Learning-Based Computer Vision Framework for Predicting Retroreflectivity of Road Signs

Technology Transfer Activities

by

Judith L. Mwakalonge
(South Carolina State University; jmwakalo@scsu.edu; 803-536-8321.
134 Engineering & Computer Science Complex, SCSU, Orangeburg, SC 29117)

Denis Ruganuza (South Carolina State University)

Methusela Sulle (South Carolina State University)

Gurcan Comert (North Carolina Agricultural and Technical State University)

September 2024

Center for Connected Multimodal Mobility (C^2M^2)

CLEMSON UNIVERSITY

SC State University | The Citadel, The Military College of South Carolina | University of South Carolina | Benedict College

200 Lowry Hall
Clemson, SC 29634

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by the Center for Connected Multimodal Mobility (C^2M^2) (Tier 1 University Transportation Center) Grant, which is headquartered at Clemson University, Clemson, South Carolina, USA, from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

Non-exclusive rights are retained by the U.S. DOT.

ACKNOWLEDGMENT

This project is sponsored by the U.S. Department of Transportation (USDOT) through Center for Connected Multimodal Mobility (C^2M^2) Tier 1 University Transportation Center (UTC). The transportation Program of South Carolina State University has administrated the research works.

Table of Contents

Technology Transfer Activities

1 Conducted Research Study and Findings

We conducted a literature review to understand how the retroreflectivity of traffic signs deteriorates over time and what factors affect the deterioration of the traffic signs. We also investigated traffic sign maintenance strategies that maintenance agencies use and what models have been developed to predict the retroreflectivity values or deterioration of road traffic signs. Lastly, we collected data from road signs in Orangeburg County, SC, including the signs' images, and use the data and images to develop a deep learning model to predict the retroreflectivity values of the signs. This study will help understand traffic sign deterioration and create an optimal replacement strategy while enhancing safety.

- First, for conducting a literature review to study retroreflectivity predictive models of traffic signs, we searched through literature using Google Scholar for journals, conference papers, technical reports, dissertations, and theses. We found that most studies have applied traditional statistical models, traditional machine learning, and neural networks to predict retroreflectivity with input variables such as sign age. The potential of deep learning models such as convolutional neural networks (CNNs) using computer vision technology has not been explored. Also, environmental factors such as air temperature, and humidity which may have an impact on retroreflectivity degradation have yet to be integrated with such models. This gap offers an opportunity to develop a deep learning model integrated with computer vision for retroreflectivity estimation.

- From the outcomes of the literature review, we collected road traffic signs data in Orangeburg, SC. A total of 586 traffic sign data was collected before pre-processing and signs with missing data were omitted from the collected data set before analysis and model development.

- After data cleaning and preprocessing, to develop a deep learning model to estimate the retroreflectivity values, different models with different architectures were used and the model's performance was assessed. A fusion model with image and tabular data as inputs to predict the retroreflectivity values (Background and Legend) was found to perform better in comparison to other models.

2 Outputs

We have completed the initial phase of our research project, which involved a literature review and data collection, conducted several analyses, and obtained results. We plan to share this research through conference presentations and journal articles. Below, we have outlined the dissemination activities for this project.

2.1 Accomplished Outputs so far

Conference Poster Presentation

We had the opportunity to present our research findings at the Center for Connected Multimodal Mobility Conference (C^2M^2) in August 2024. Additionally, our paper has been accepted for presentation at the 104th Transportation Research Board (TRB) Annual Meeting, which will take place from January 5–9, 2025.

C2M2 Report

Mwakalonge, Judith L.; Ruganuza, Denis D., Sulle, Methusela, Omulokoli, Paul, Siuhi, Saidi; and Comert, Gurcan (2024). Deep Learning-Based Computer Vision Framework for Predicting Retroreflectivity of Road Signs. Center for Connected Multimodal Mobility (C2M2) Tier 1 University Transportation Center (UTC).

2.2 Future Outputs

Peer-Reviewed Journal Article

We are writing a journal article based on what we have done so far in this project for submission to Journals such as Sage Public Works Management & Policy. The papers will focus on the possibility of applying deep learning models and image detection techniques to predict traffic signs' retroreflectivity values and status to help transportation agencies manage traffic signs while improving safety and reducing costs.

Conference Poster and Podium Presentation

We plan to present our research work at conferences, e.g., Lifesavers conferences.

3 Outcomes

The research has two important outcomes which are given below:

3.1 Literature Review-based Outcome

Our research has discussed the advancements made in predicting the retroreflectivity values of traffic signs using different models and has highlighted those early studies relied on traditional statistical models. The linear and regression models had limited predictive powers, achieving R^2 values between 19% and 52%. The advancement of machine learning models outperformed the previous models with neural networks achieving an accuracy of 65.27%. By 2021, deep learning models, such as neural networks, achieved an R^2 value of 97.6%, outperforming polynomial regression models with an R^2 of 75.9%. In 2022, machine learning algorithms like Random Forest,

Support Vector Machines, and artificial neural networks were able to achieve higher predictive performance, with F1 scores of up to 98%. However, these approaches depend on data collected from handheld retroreflectometers, and no studies have investigated the use of computer vision techniques for retroreflectivity estimation from traffic sign images. Furthermore, the impact of environmental factors like air temperature, humidity, and pollution on retro-reflectivity degradation remains underexplored. This gap provides an opportunity for the development of deep learning models incorporating computer vision and environmental parameters to enhance retro-reflectivity prediction.

3.2 Model-based Outcome

We have developed and analyzed the performance of different models with different architectures, and ultimately proposed a model that fuses deep learning techniques with image and tabular data inputs. The proposed model leverages the EfficientNet-based architecture for image feature extraction and combines it with tabular data to predict retro-reflectivity values with reasonable accuracy compared to other developed and analyzed models. With a test loss of 6,783 and an MAE of 57.56, the model shows that its predictions, while not perfect, are reasonably close to the actual retro-reflectivity values, capturing the general trends in the data. The R^2 value of 0.79 suggests that the model explains 79% of the variance in the retro-reflectivity values. This level of performance is encouraging, as it demonstrates the model's potential to automate the detection of road signs that no longer meet the required retro-reflectivity standards.

4 Impacts

We hope this research work will create a meaningful impact on traffic sign maintenance. According to the findings, possible implications of our research can be noted as follows:

4.1 Enhancing road safety, Cost- Effective Maintenance, and Data-Driven Infrastructure Management

This research contributes to accurately predicting the retro-reflectivity of road signs and with further improvements may enable transportation agencies to identify signs that need replacement without relying on costly, labor-intensive manual inspections and can lead to proactive sign replacement strategies ultimately helping transportation agencies maintain safer roadways with greater efficiency.