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Case Study

Enhancing Road Safety: The Impact of Wet-Reflective Pavement Markings on Lane Detection Systems

Disclosure

This document contains information sourced from multiple studies and reports, the findings, methodologies, and recommendations presented are based on these sources. Readers are encouraged to refer to the original studies for detailed insights and data. This case study aims to provide an overview of the impact of wet-reflective pavement markings on road safety and automated driving systems.

Introduction

Automotive traffic contributes to serious issues such as air pollution, energy consumption, traffic accidents, and congestion. Driving assistance and automated vehicle systems are expected to mitigate some of these problems by reducing traffic accidents. Lane keeping assistance systems and lane departure warning systems, which rely on recognizing pavement markings using image processing technologies, are among the most popular commercialized systems. Despite advancements in deep learning and AI algorithms, poor visibility of pavement markings in adverse conditions can still hinder the performance of these systems. High-visibility pavement markings, designed to have high retroreflectivity, have been proposed to address this issue.

This study evaluates the performance of nine different pavement markings compared to ordinary pavement markings under various conditions. Furthermore, it highlights the benefits of upgrading to wet-retroreflective pavement markings, which have been shown to reduce crash rates and improve safety.

Objectives

The study aims to evaluate the performance of highly retroreflective pavement markings under various weather conditions and times of day, demonstrating their effectiveness in improving image processing performance in challenging conditions. Additionally, the study promotes upgrading existing markings to wet-retroreflective pavement markings to enhance safety and visibility.

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Main finding

Upgrading existing pavement marking solutions to wet-retroreflective pavement markings can extend the operational range of automated driving systems to include rainy, dark conditions.

Methodology

The experiments were conducted on an AIST test track in Tsukuba, Japan. Ten different pavement markings were installed in straight lines, each 80 meters long with 3.5-meter intervals between them.

Testing

The pavement markings tested include:

1. All-weather thermoplastic pavement marking with large-size elements
2. All-weather thermoplastic pavement marking with increased amounts of elements
3. Thermoplastic road marking paint
4. Durable pavement marking tape 2
5. Durable pavement marking tape 1
6. All-weather thermoplastic pavement marking
7. Temporary pavement marking tape
8. Brightness controlled tape (Effective reflection area 30%)
9. Brightness controlled tape (Effective reflection area 20%)
10. Brightness controlled tape (Effective reflection area 10%).

A test vehicle equipped with a camera (Allied Vision, MAKO G-319) was used to capture images of the pavement markings. The image processing algorithm for lane detection was developed using OpenCV. The experiments were performed under different weather conditions (sunny and rainy) and times of day (daytime and nighttime). The tests also included varying precipitation levels during nighttime conditions.

Key Findings

In the daytime, all pavement markings were detectable under both sunny and rainy conditions. However, different results were observed under nighttime conditions:

- Sunny, nighttime: Most pavement markings were detectable with high-beam headlights, except for those with reduced white areas (Lines 9 and 10).
- Rainy, nighttime: Only the all-weather pavement markings (Lines 1, 2, 4, and 5) were consistently detectable. These markings had special retroreflection properties that enhanced their visibility despite the challenging conditions.

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The study measured the reflection brightness and intensity of the pavement markings to determine the necessary values for effective detection by image processing systems. The recommendations for road markings in the EU state that they should never drop below 150 mcd/lx/m² at night under dry conditions and below 35 mcd/lx/m² at night under wet and rainy conditions. Based on the experimental results, the road markings should never drop below 295 mcd/lx/m² under wet conditions with low beam and below 200 mcd/lx/m² at night under wet conditions with high beam.

Discussion

Under rainy night conditions, some lane markings were invisible, while the all-weather lines were clearly recognizable. Human drivers can better recognize lane markings than image processing systems, as they use visible information and make predictions based on the surrounding environment.

The availability and reliability of automated driving and driving assistance systems are significantly reduced when general (or not all-weather) markings are used under rainy night conditions. High-performance cameras, advanced sensors, and upgraded algorithms are expected to improve recognition performance in the future, but their widespread adoption will take time.

The all-weather markings evaluated in this study have high detection performance and high-visibility validity under rainy conditions.

These markings not only assist human drivers and contribute to driver safety but also extend the range and applicable environment of image processing systems without waiting for breakthrough technology.

Safety Benefits of Upgrading to Wet-Reflective Pavement Markings

Upgrading existing markings to wet-reflective pavement markings has been shown to significantly enhance road safety, particularly under adverse weather conditions. A pooled fund study conducted by the Federal Highway Administration evaluated the effectiveness of wet-reflective pavement markings across multiple states, including Minnesota, North Carolina, and Wisconsin.

The study found statistically significant reductions in crashes for various types of roads and conditions[2]:

- **Freeways:** The combined results indicated reductions in injury and wet-road crashes, with estimated crash modification factors (CMFs) of 0.881 and 0.861, respectively.
- **Multilane Roads:** Statistically significant reductions were estimated for total crashes (CMF = 0.825), injury crashes (CMF = 0.595), run-off-road crashes (CMF = 0.538), wet-road crashes (CMF = 0.751), and nighttime crashes (CMF = 0.696).
- **Two-Lane Roads:** Although the sample size was too small to detect statistically significant effects, there were indications of safety benefits for wet-road crashes.

The study also highlighted the cost-effectiveness of wet-reflective pavement markings, with benefit-cost ratios estimated at 1.45 for freeways and 5.44 for multilane roads, suggesting that the treatment can be economically viable even with conservative assumptions on cost, service life, and the value of a statistical life.

Recommendations

For future works, due to the lack of experimental data on pavement markings, more experiments should be performed under a greater range of conditions, especially with different precipitation values. The durability of the proposed pavement markings should also be investigated under several conditions and different ways of use.

Transportation authorities and road safety organizations are encouraged to adopt wet-reflective pavement markings to improve safety and support the advancement of automated driving technologies. By investing in these innovative solutions, we can pave the way for safer roads and more reliable Advanced Driver Assistance System (ADAS) performance.

References

1. Hashimoto, N., & Takinami, Y. (2021). Evaluation Experiments of Lane Markers for Lane Detection Systems under Several Conditions. National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, Japan.
2. Lyon, C., Persaud, B., & Eccles, K. (2015). Safety Evaluation of Wet Reflective Pavement Markers. Federal Highway Administration, Report No. FHWA-HRT-15-065.

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