

Proceeding Paper

Analysis of LDWS Recognition Rate According to the Aging of Road Marking [†]

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Abstract: In recent years, research on self-driving cars has been conducted in connection with road infrastructure in order to overcome the limitations of self-driving, such as the video detecting capability at day and night time. This study evaluates the operation of the lane departure warning system (LDWS) used in autonomous vehicles on real roads, as influenced by the aging of the road markings. The performance of the road markings was measured using the retro-reflection coefficient. Since there are restrictions on experiments on real roads, the experiment was conducted using the driving track of the Korea Institute of Civil Engineering and Building Technology while degrading the reflective performance of constructed road markings of different colors. The results indicated that there was no perceiving problem with the recognition rate of LDWS in day and night situations, but some situations occurred that depended on sun phantom or weather conditions.

Keywords: retro-reflection coefficient; lane departure warning system; connected autonomous vehicle; road marking performance

1. Introduction

Lane departure warning systems (LDWS) were first introduced in the early 2000s, and initial studies found that the recognition rate was relatively low. For example, a study published in 2003 found that LDWS had a recognition rate of only 40–60% [1]. However, over the years, advancements in technology have led to significant improvements in the recognition rate of LDWS. A study published in 2016 found that the recognition rate had improved to over 90%, and more recent studies have reported even higher recognition rates [2]. It is worth noting that the recognition rate can depend on various factors, such as the type of road, weather conditions, and the quality of the road markings [3]. However, overall, it seems that the recognition rate of lane departure warning systems has been steadily improving over time [4]. However, there are no studies about performance changes of lane departure warning systems based on the aging of the lane markings. Therefore, in this study, we tried to examine the change in the recognition rate of the LDWS according to the aging of different colors of lane marking and variations in retro-reflectivity.

2. Experiment Method

2.1. Experiment Conditions

The experiment was conducted at the Yeoncheon SOC Demonstration Center of the Korea Institute of Construction Technology (KICT), where there is a weather reproduction demonstration test section that allows for the artificial expression of weather conditions, such as day and night. This section is crucial for testing autonomous vehicles. LDWS function tests were performed to meet the safety driving requirements of autonomous vehicles by the Ministry of Land, Infrastructure, and Transport (MOLIT).

The test conditions for the experiment included an air temperature range of 0–45 °C in the test furnace. The Lane Keeping Mode was set to a test-driving speed of 60 km/h, as



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recommended by MOLIT. These conditions were chosen to test realistic driving scenarios and to ensure accurate results.

2.2. Configure Autonomous Vehicle Speed and Trajectory

The vehicle speed was set to 60 km/h, which is a feasible speed for the LDWS to detect and respond to lane departures. The lateral lane departure of the vehicle was set to a departure angle of 5.01° , which was calculated using the tangent of 3.5 divided by 40. Additionally, the lateral speed of the vehicle was set to 1.458 m/s, which means that the vehicle was moving at a steady speed while staying within the desired lateral departure angle.

This indicates that the configuration of the autonomous vehicle's speed and trajectory took into consideration the painted and unpainted sections of the lane. Figure 1 describes the experimental test area and vehicle trajectory.

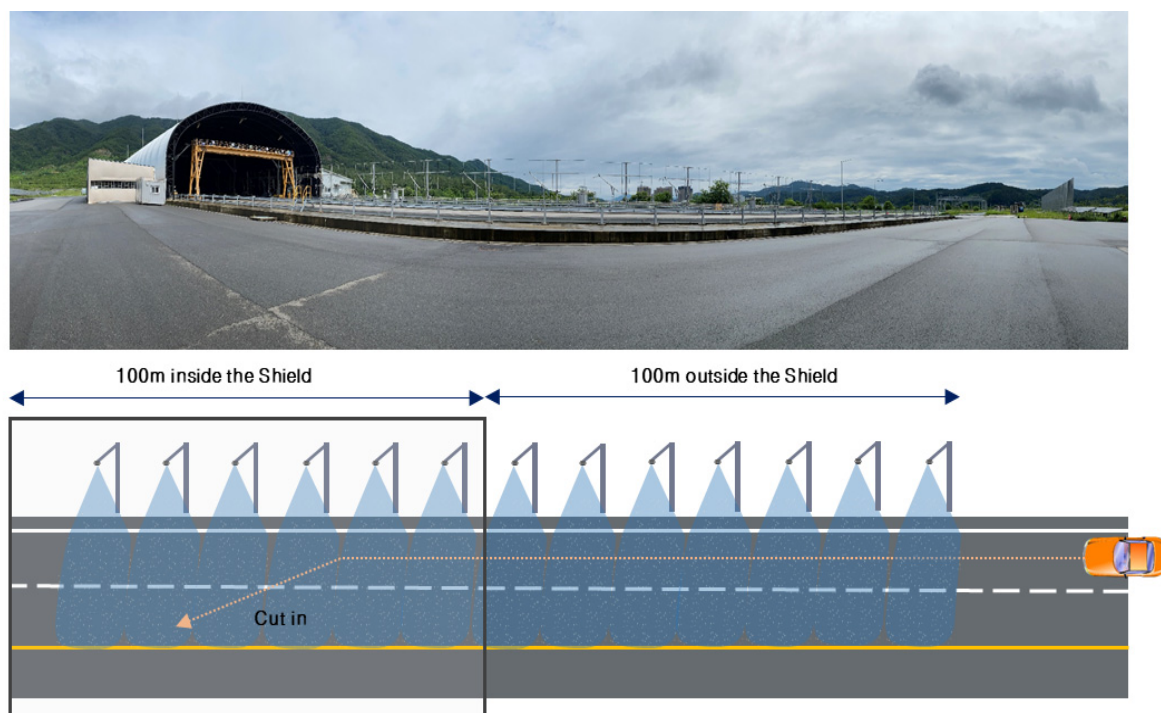


Figure 1. The Experimental Area of the Yeoncheon SOC Demonstration Center of KICT.

2.3. Construction of Road Lane Markings and Composition of Day/Night Experiments

The road surface marking construction was set according to the standards presented in the traffic road marking installation and management manual for the median line (yellow), lane (white), and exclusive lane (blue) using line types and specifications [5]. The following parameters were used for the construction:

1. Paint Length (L1): 300 cm
2. Empty Length (L2): 300 cm
3. Width (W): 15 cm

The experiment was conducted during the day from 12:00 to 15:00 and at night after 21:00 (with lighting on & off). Figure 2 shows the aging process, which was implemented using a grinding machine, and (b) describes the measurement of the reflection coefficient after aging.

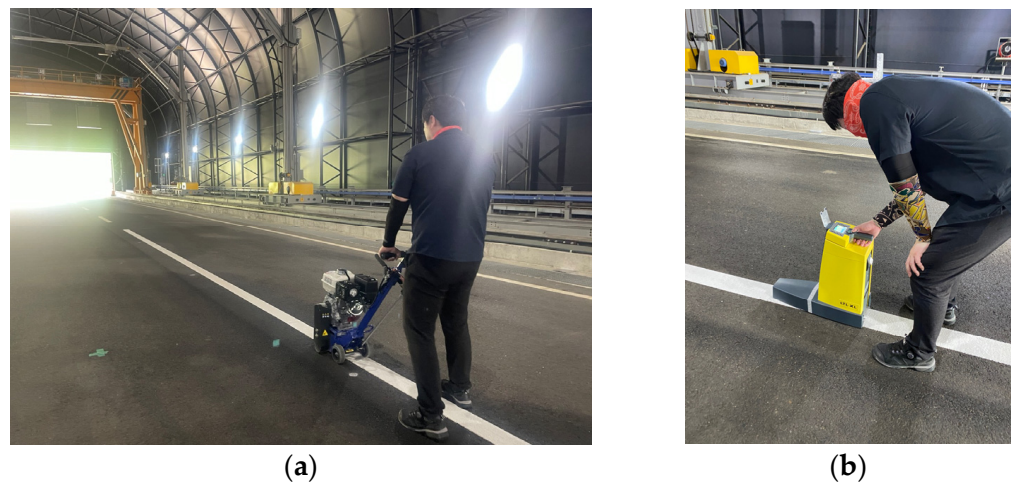


Figure 2. Experiment preparation: (a) aging machine and (b) retroreflection coefficient measuring machine (LTL-XL).

2.4. Construction of Roadlane Markings and Composition of Day/Night Experiments

Equation (1) is used to calculate the recognition rate (%) of LDWS for road lane markings based on the experimental results. The equation employs the number of road marking recognition counts and the total driving count to compute the recognition rate as a percentage.

$$\text{LDWS recognition rate} = (\text{No. of Warning} / \text{Total Exp. No.}) \times 100 \quad (1)$$

The experimental results were based on a sufficient number of driving scenarios to ensure the calculated recognition rate's reliability.

3. Test Results

LDWS experiments were conducted on road markings, and after the tests, the markings were ground to simulate road surface aging. The LDWS experiments were then conducted again to evaluate the impact of aging on the effectiveness of the LDWS system.

Based on the experimental procedure, the retroreflective coefficients of white, yellow, and blue road markings were initially measured as 365, 200, and 212 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$, respectively. To test the effect of aging on the retroreflective performance of the road markings, the markings were ground 2, 4, and 8 times, and aging was conducted. After aging, the retroreflective coefficients of white markings decreased to 253, 142, and 104 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$, respectively. For yellow markings, the retroreflective coefficient decreased to 164 and 76 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$ after two and four rounds of grinding, respectively, and it dropped to below 45 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$ after eight rounds of grinding. The retroreflective coefficient of blue markings decreased to 132, 62, and 47 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$ after two, four, and eight rounds of grinding, respectively.

On the demonstration tests conducted for white, yellow, and blue lanes, the following results were obtained:

For white lanes, 100% lane recognition was successful in daytime conditions. However, in nighttime conditions, there was a decrease in the lane recognition rate related to the decrease in retroreflection coefficient. Despite this decrease, a recognition rate of over 90% was still achieved regardless of whether there was night lighting or not, even in the situation of aging road markings.

For yellow lanes, a 100% lane recognition rate was achieved in all daytime conditions. However, it was confirmed that a recognition rate of 90% was secured at night (with or without lighting) when the retroreflective coefficient approached the repainting standard of 70 $\text{mcd}/(\text{m}^2 \cdot \text{Lux})$.

For blue lanes, a 100% lane recognition rate was shown in daytime conditions. In nighttime conditions, a 90% lane recognition rate was shown, regardless of the presence or absence of lighting.

Overall, the results suggest that the retroreflective coefficient of road markings is an important factor in determining the effectiveness of lane recognition systems, especially in nighttime conditions. However, the lane recognition rate can still be maintained at a high level even in situations where the retroreflective coefficient has decreased due to aging road markings.

4. Conclusions and Further Study

The study found that LDWS installed in autonomous vehicles resulted in a 100% recognition rate of road markings during the daytime and a 90% recognition rate at nighttime, where the recognition rate refers to the LDWS's ability to detect road markings. It was noted that the same 90% recognition rate was observed, regardless of the presence or absence of lighting at night time, which is thought to be due to the headlights of the vehicle. Currently, the minimum retroreflection coefficient is set based on the standard for a general driver, so it is not a problem for LDWS for driving support. However, future self-driving cars will require higher accuracy, and additional experiments will be needed to evaluate the performance of LDWS in adverse weather conditions, such as rain and fog, which were not tested in this study.

It is crucial to test the performance of LDWS under various weather conditions to ensure efficiency and safety in real-world scenarios. Therefore, experiments should be conducted in rainfall and low-to-moderate fog conditions to evaluate how the LDWS system responds to these challenging conditions and to identify potential areas for improvement. We plan to conduct experiments according to the conditions of rainfall intensity and medium-low visibility fog.

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