HIGH PERFORMANCE PAVEMENT MARKINGS ENHANCING HUMAN, CAMERA AND LIDAR DETECTION

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ABSTRACT

A Safe System Approach is built on several complementary safety layers provided by the car, the road infrastructure and improved driver behavior, through education or enforcement. Historically road markings and traffic signs have focused on the driver impact by human detection and making the infrastructure better visible in all weather and traffic situations.

More recently the adaptation of the road to machine vision has become very relevant due to the developments in advanced driver-assistance systems (ADAS) and autonomous vehicles (AV). Better road markings are required to improve the confidence of ADAS, and secondly to lay the base for higher levels of vehicle automation. The General Safety Regulation in the EU already mandates ADAS in new vehicle models. In 2024 all new registered vehicles need to be equipped with several ADAS, including Lane Keeping Assist (LKA) or Lane Departure Warning (LDW) systems.

The human eyes and cameras are the sensors currently used have limitations in detecting road markings under certain conditions e.g., glare from sunlight or oncoming vehicles, rain, fog, low light nighttime conditions. All-weather performing (AW) tapes contain the latest developed high optics road markings, made of a mix of higher refractive index (R.I. mix 1,9 and 2,4) beads to provide reflectivity both in dry and wet condition when compared to the conventional (traditional) paint road markings with the optics of R.I 1,5 to 1,7 that perform mainly under dry conditions. This paper covers how better or improved road markings can influence both human and machine vision, with focus on camera and Light Detection and Ranging (LiDAR) sensors.

It has been determined that high performance (RI>1,7) road markings help to increase the level of detection by both camera and LiDAR sensors, as well as human eyes. Particularly an All-Weather performing road marking tape was detected from significantly longer distances in wet and rainy conditions compared to traditional markings.

1. INTRODUCTION

The fast-growing automation of road traffic demands better accuracy with regard to vehicle localization. Independent systems in the vehicle need to acquire or generate data to support higher degrees of automation. Due to the long introduction time of technology, consumer acceptance and adequate regulatory framework, road infrastructure will continue to serve human driving as well.

The road markings key properties are their visibility under various conditions and this made possible by using glass or ceramic beads. The common examples are preformed tapes, paints, and hot or cold plastics. Daytime visibilty is created by contracting colours (measured as luminance coefficient under diffusion illumination Qd) whereas for nighttime visibility, the vehicle' headlamps are essentail to create retroreflectivity, measured as coeficient of retroreflected light RL. Figure 1 illustrates how humans manages to detect road markings during night and day.

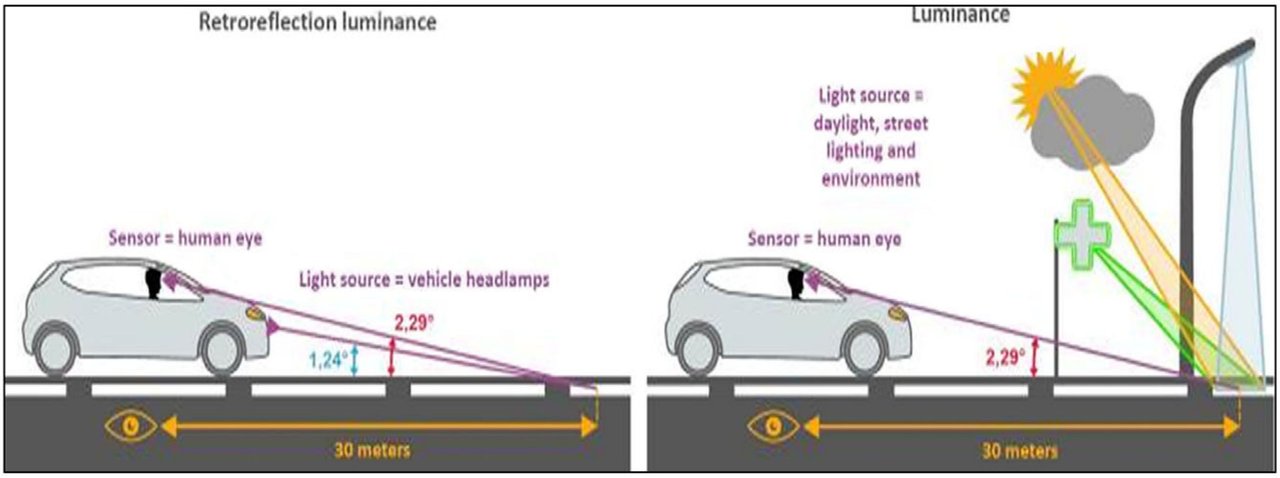


Figure 1: Retro-reflection based luminance (RL, RW or RR) and diffuse luminance (Qd) of road markings can be measured according to CEN EN1436

Global Navigation Satellite Systems (GNSS) are used to acquire localization information, but the accuracy is not high enough for automated driving. Camera systems are broadly used, creating an environmental model, but in various situations have limitations. Radar systems are a good complement to acquire additional information of the environment and will increase the needed level of redundancy. Especially the velocity information of dynamic objects could be read out very easily.

Nowadays LiDAR systems are added in cars to complete the range of sensors which are able to provide additional information for the automated driving function. As it is sending out its own signal in a near-Infra Red (N-IR) laser wavelength, it can calculate the distance to an object by measuring the time the signal moves back and forth to and from the sensor. The LiDAR can also eliminate the potential detection failures caused by other light sources, both artificial and sunlight, as seen in traditional camera systems. While radar systems function in a defined giga-frequency range and only detect larger objects. [1] [2] [6] [7].

This paper covers how road markings properties and performance impact the two most common technologies of machine vision and human detection:

1. The “Rainvision” covers a human impact study, where drivers were exposed to different weather conditions.
2. A camera research project with VEDECOM France.
3. A small LiDAR research project at HTW University of Dresden.

3M company was part of the research team to all 3 studies.

2. “RAINVISION” PROJECT: HUMAN IMPACT STUDY COVERING DRY, WET AND RAINY ROAD CONDITIONS

Most of the road markings are visible during daytime except when they are worn out or badly damaged that drivers would not see them, the matter become even more dire when drivers have to travel during the night and weather conditions changes from dry to wet or rain. Rainvision, covers a 3-year European Commission funded study where 3M Germany was part of the international consortium (http://www.rainvision.eu/).

Rainvision aims were to study the influence of road markings on driver behaviour, by mainly analysing how different age groups (young vs middle vs old) and different gender groups (male vs female) adapt their driving behaviour to changes in visibility and retro reflectivity of road markings under all weather conditions, (i.e., dry, wet, wet and rainy) during night time driving. The driver behavior expressed in terms of travel time and how comfortable they feel as they drive through the test track.

Following an exploratory driving simulation test in France, the “Rainvision” project moved to a full-scale night driving test on a Test Track in Austria. During several nights about 90 people, evenly distributed over 6 groups based on gender and age, drove the test track either equipped with poor (Baseline); newly applied Type I (MMI) and or new applied Type II (MM II) markings. The drivers consisted of 3 age groups (young (20-40yrs) – middle aged (41-60yrs) and older drivers (>61yrs) and each group further sub-divided in male versus female. All drivers were subject to an eyesight-test.

On separate nights, 3 types of road marking were evaluated on the test track, namely:

- Baseline condition (Already present old, poorly visible or non-reflective).
- Marking material MM I (Newly applied, Type 1, only dry-reflective).
- Marking material MM II (Newly applied, Type 2, wet-reflective).

For statistical purpose and avoiding pre-knowledge or routine, the 90 test drivers were exposed to the test conditions in a different order. Out of each group, 5 drivers started with “old, poorly visible”, 5 drivers started “MM1” and 5 drivers started “MM2” type marking first. Additionally, a questionnaire was used to measure driver’s subjective comfort levels after each test run and the response are represented in the Figure 2 below.

Also, the vehicle was modified to semilate rainy conditions (water sprayed on windshield to trigger the wiper). These vehicles were also equipped with the necessary sensors and cameras to monitor speed and various forces.

A low score means positive experience for the participant. Driving at night make people uneasy it get worse when it is raining. The biggest improvement in driver experience was seen when driving on wet and rainy condition. Stress level reduced and comfortability increase with the change from non reflection to better performing road markings, see Figure 2. Drivers paid attention to the road and the road looked well arranged as the could see further. It could be clearly shown that both reflective marking materials are perceived more comfortable, and guiding compared to the non-reflective marking.

Regarding driving behaviour by means of speed choice, participants drove slowest in the poorly visible condition, faster under condition with applied standard dry-reflective marking material, and even slightly faster under the condition with advanced wet-reflective material. This is confirmed by the reduction in lap time for both male and female in all age groups participants when the material was changed from non-reflective, dry reflective and wet reflective road markings, see Figure 3.

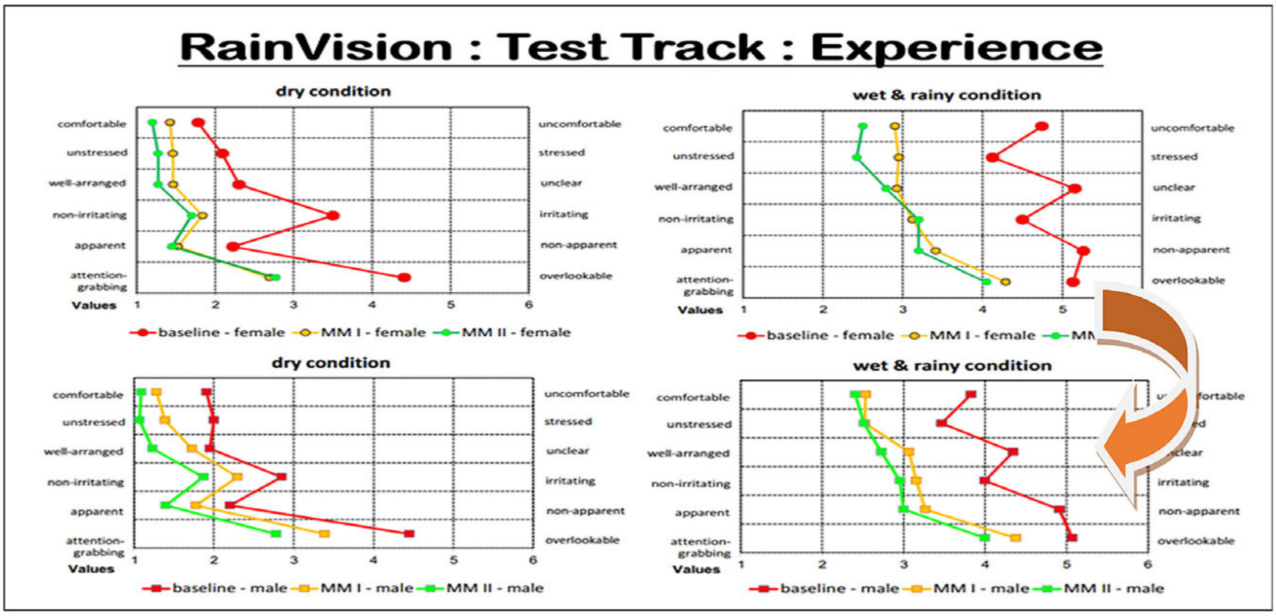


Figure 2: The interviews concluded that improved visibility and look ahead distance by the markings bring a general increase of driving comfort and confidence (a lower score means a more positive experience)

The eyesight gets poorer with age which also impacts the diminishing confidence to drive at night. The biggest gain in relative speed was noticed with the elderly drivers. The extra road markings visibility, provided them with more confidence and they partially closed the gap in speed with the other drivers. The reduction lap completion further confirmed that the drivers were gaining in preview time of the ahead. Thus, improving detection of the lane path.

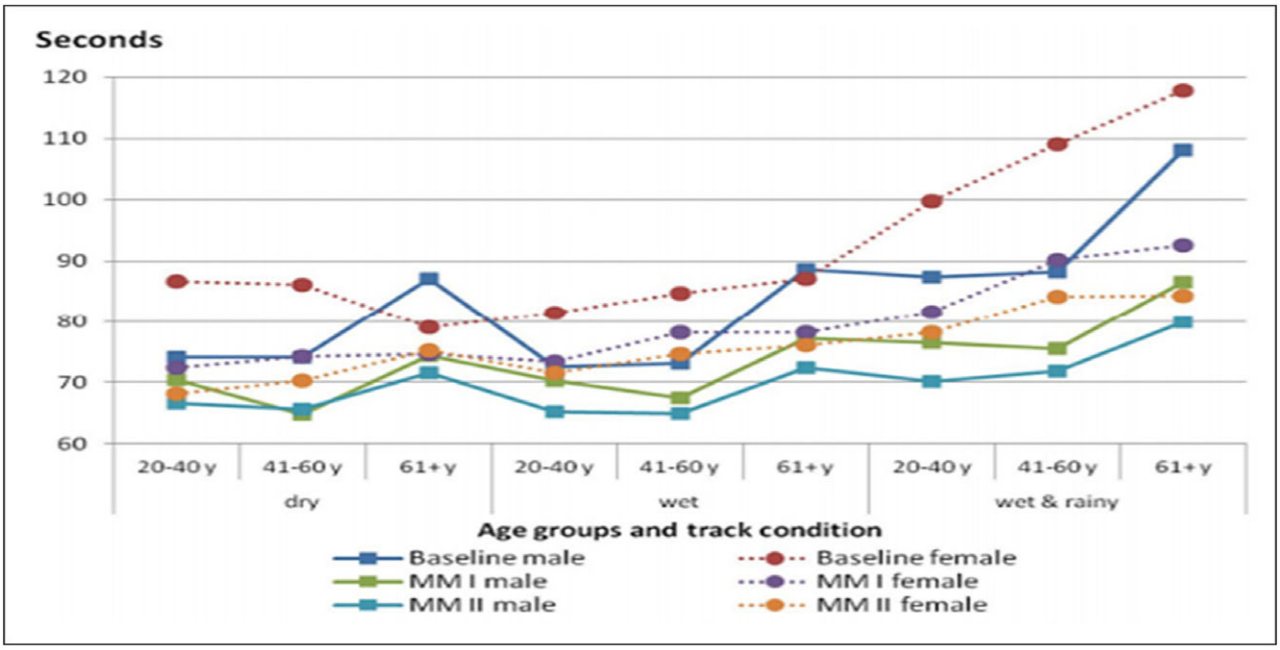


Figure 3: Lap times (in seconds) to complete the testtrack. By age group, marking type and weather condition

3. CAMERA SYSTEM FOR ROAD MARKING DETECTION

Camera systems have been introduced for several year now, to help navigate vehicles on our roads. Simulations have been done to evaluate the role of road marking. The aim of the VEDECOM-3M study is to estimate the performance of different road markings under various weather conditions by evaluating the detectability with camera based ADAS. Specifically, the contrast between the road surface and the road marking is measured by using a camera as an indicator of how easily or not they would be detected by ADAS such as a LKA system in real operation (Bares & Redondin, 2020). Furthermore, for confirmation of performance of the reflective products used, daytime luminance Qd and and retroreflectivity RL were measured over time under different conditions as per EN1436.

In this project, seven different road marking products were tested, analyzed and compared. The products, provided by 3M were installed at Versailles Satory on a test track near VEDECOM.

The chosen products are four structured preformed road marking (tapes) and three different traditional flat liquid markings (paints). The preformed road markings tapes were white, yellow (with reflective bead ranging from (RI 1.7 to 2.4); black preformed road marking tape (with reflective no beads). The paint markings were, retroreflective white paint (with bead RI 1,5), a non-retroreflective white paint, and an aged non-retroreflective (simulated) white paint. The performance of the road marking material increase in luminance and reflectivity as the RI increase from 1.5; 1.7 and 1.9 under dry conditions whereas the RI on 2.4 assist inperformance during wet or rainy condtions.

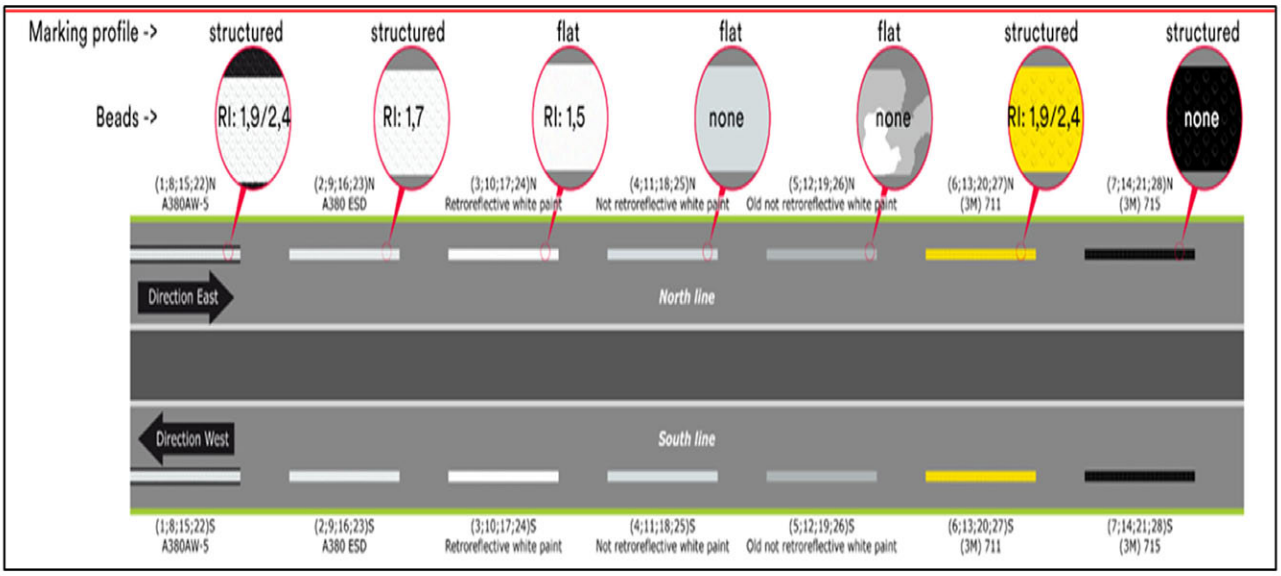


Figure 4: Schematic view of the Satory test set up. The above set of markings is repeated 4 times to form a full straight lane of 225 m

Several different use cases were chosen to represent different environmental conditions (day, night, weather) encountered by a vehicle. The road markings have been applied on both edges of the test track and observed and tested in two directions, indicated as East and West in Figure 4 and Figure 5. This is especially relevant with low sunlight, to analyze use cases as driving against the Sun, or the Sun from behind the vehicle.

Figure 5: The Satory Test Track right after installation on December 2nd 2019

The VEDECOM perception vehicle, see Figure 7, was chosen to perform this study and more specifically the camera system embedded in the vehicle, as it is widely used in typical ADAS in various standard vehicles.The installed LiDAR sensors have not been used to collect road marking data, but only to remove obstructing information on the final (enhanced) image for the visual camera (Figure 6). This dedicated, non-commercial methodology has been developed in order to maximize the detection of the road marking section by the on-board camera so as to measure accurate contrast values.

Figure 6: Real and final (enhanced) image to detect markings for contrast data

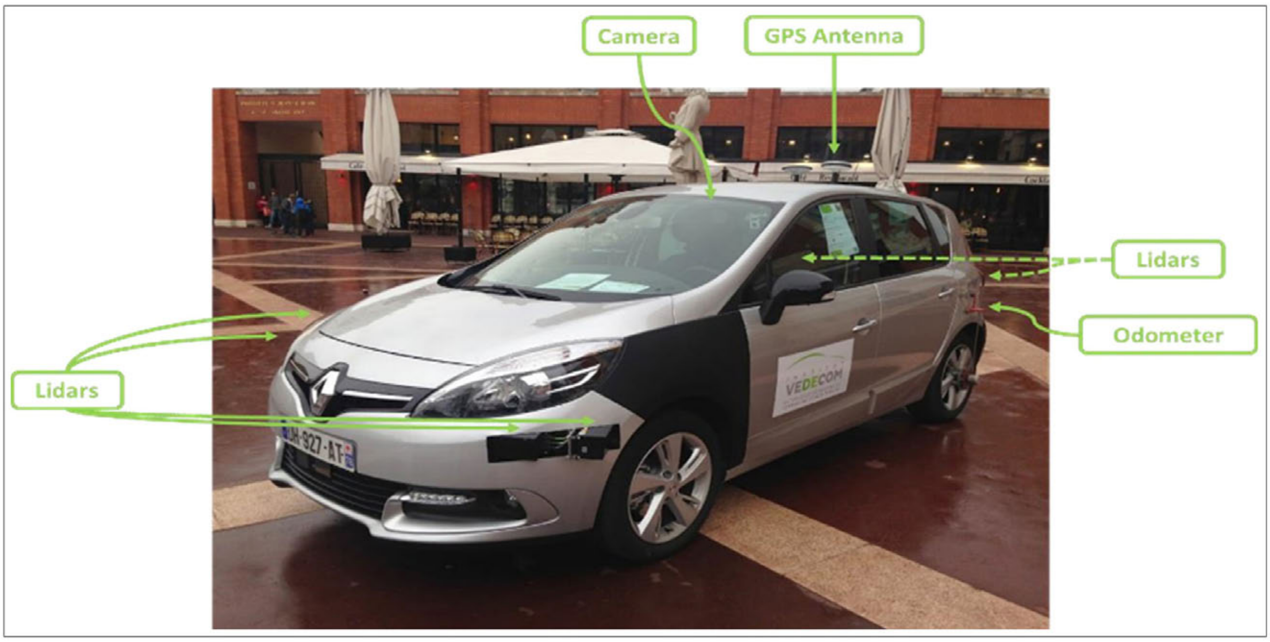
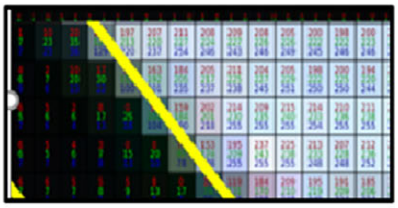


Figure 7: Picture of the perception vehicle

Multiple vehicle camera systems and the algorithm were combined in order to acquire the maximum possible data for this study. The focus of the study is to compare the different markings, not to see if they provide minimum threshold contrast for a commercial LKA system. Datasets were recorded with the perception vehicle over several months under a variety of environmental and lighting conditions in order to acquire information for all relevant use cases.

All processing, performed in order to analyze the detectability of the different roadmarkings, were done offline. The road markings were detected and analyzed using a line detection algorithm developed at VEDECOM. It allows us to extract the lines around the vehicle from the previously recorded image. The extraction process begins by removing the obstacles, detecting the lines and then the road markings composing them. It continues by extracting the identified markings and eventually evaluating them using the contrast with the surrounding road surface and recorded as Weber Contrast. Weber Contrast values for each marking are calculated pixel rgb-values of the marking and the adjacent road surface (Figure 8).



rgb pixel values converted to luminance

Weber Contrast:

$$W_c = \frac{L_m - L_b}{L_b}$$

Wc : Weber Contrast
Lm : Luminance of the Marker
Lb : Luminance of the Background

Figure 8: From pixel red/green/blue (rgb) values to Weber Contrast

Table 1 shows the Weber contrast values that have been found for the seven different pavement markings and the various use cases. The use cases have been clustered for the ‘closest standard equivalent’, meaning the correlating performance characteristic in EN 1436. To obtain sufficient resolution and pixel quality, all data points were taken at 15m in front of the sensor camera. At this distance also diffuse illumination by the car headlights will help to the detect the markings.

Table 1: Average Weber Contrast per marking material and use case. Values calculated based on detection rate (often limited data collected – see Table 3 below)

Closest EN1436 reference	Use case	Road Marking						
		White (R.I. 1,9+2,4)	White (R.I. 1,7)	Paint + beads	Paint without beads	Old paint without	Yellow (R.I. 1,9+2,4)	Black without beads
Qd	Standard condition	2,1	3,07	2,7	3,38	0,69	1,29	0,02
	Glaring sun dry	2,23	2,58	2,16	3,15	0,64	1,33	0,73
	Midday	1,93	3,05	2,43	3,13	0,64	1,15	0
	Day Wet	1,92	2,88	2,26	2,46	0,61	1,08	0
	Day Light Rain	1,35	1,99	1,45	1,54	0,39	0,77	0
R_L	Twilight Cloudy	4,92	4,15	3,33	3,57	0,95	2,44	0
	Night Dry	15,2	15,03	9,17	3,69	1,51	7,87	0
RW	Night Wet	51,93	19,04	11,4	5,63	2,57	28,91	3,87
RR	Night Light Rain	19,58	7,75	4,26	1,94	1,48	12,72	3,91
	Night Heavy Rain	5,02	1,28	0,53	0,06	0,15	1,99	0,15

Furthermore, performance of road markings, were measured as Qd, RL for the dry condition, RW for wet and condition to show how reflective properties impact on contrast ratios, see Table 2.

Table 2: Daytime luminance Qd and Nighttime Retroreflection RL or RW measured according to EN1436 at intervals during the test period

Conditions	Light Rain		Dry Weather		Dry Weather		
Measurement date	27/01/2020		30/06/2020		24/02/2021		
Measured value (mcd.m^{-2}.lux^{-1})	R_L	Qd	R_L	Qd	R_L	Qd	RW
Preformed Structured White (R.I. 1,9+2,4 beads)	435	221	755	163	653	147	356
Preformed Structured White (R.I. 1,7 beads)	83	228	200	244	333	242	65
Flat White Paint (R.I. 1,5 beads)	65	275	169	206	166	153	33
Flat White Paint (No beads)	26	287	53	262	41	235	-
Old Flat White Paint (No beads)	17	144	38	99	31	85	-
Preformed Structured Yellow (R.I. 1,9+2,4 beads)	613	195	311	118	253	113	530
Preformed Structured Black (No beads)	2	68	6	24	7	40	-

The Weber contrast values with the highest results in the individual use case are indicated in dark blue in Table 1. Second and third best contrast values per use case in lighter blue.

The ten use cases in Table 1, have been further clustered into three categories in Table 3 and the % average detection rate calculated for each product. The detection rate is the actual collected data points versus the intended data points the camera should have collected (3 per line section). The missing data is due to the marking staying totally invisible on the image, even after enhancement by the LiDAR and guidance by GPS coordinate indications. The ‘Daytime’ category summarizes the use cases of standard daylight condition dry, glaring sun, midday, standard daylight in light rain and wetness. The ‘Night-time’ category summarizes driving in darkness and twilight in dry condition. The ‘Challenging Night-time’ category combines the use cases for driving in darkness during wetness, light and heavy rain.

Table 3: Average detection rate per marking material and use case category

Road marking	% Detection Rate		
	Daytime	Night-time	Challenging night-time
Preformed Structured White (R.I. 1,9+2,4 beads)	94	96	90
Preformed Structured White (R.I. 1,7 beads)	95	98	80
Flat White Paint (R.I. 1,5 beads)	98	97	60
Flat White Paint (No beads)	96	88	41
Old Flat White Paint (No beads)	85	86	19
Preformed Structured Yellow (R.I. 1,9+2,4 beads)	93	98	82

The detectability of the road marking (see Table 3) in the given scenario and use case is the decisive parameter for the ADAS functionality. It is important note that, the 96% detection rate means that only 4% of the planned data points were missed. The 19% detection rate means that the average weber contrast values in Table 1 are based on only 19% of the expected datapoints. In total 81% data points were missed as the marking could not be found back on the final image shown to the visual camera. For a commercial ADAS system, the system would not have the confidence to guide the driver below a certain detection rate (means the ability to confidently identify the marking). Most systems today tend to have low to no confidence during rainy weather.

The preformed road marking with RI 1,7 beads is best adapted for the different use cases and obtained the best overall performance. The preformed markings (white and yellow version) with RI 1,9 and 2,4 beads are able to handle the more challenging use cases of wetness and rain very well but have shown slightly lower, but still very satisfying, contrast levels than other products in standard daylight condition. The retroreflective white paint was detected in most use cases but at lower levels than white preformed marking with RI 1,7 beads and does not perform in the challenging night-time condition. The non-retroreflective white paint is only functional at dry and daylight condition.

Above results confirm the similar effect compared to human vision: the whiteness (higher Qd values) of the marking will create better daytime contrast, while the bead quality will impact nighttime retroreflection (Higher RI uptill 1,9 will improve dry retro-reflection, while RI 2,4 beads are essential for performance during rainy periods). The black preformed marking, intended as masking tape for the permanent white marking during road works, remains undetected throughout this study, except when the vehicle is facing low sunlight, which could lead to a false positive in such situations. This is created by the mirror effect of the rather glossy surface compared to a more dull road surface.

4. LIDAR SYSTEMS DETECTING ROAD MARKING

Mono or stereo cameras with suitable image processing algorithms have been used as sensors for lane detection up to now. For use in higher to fully automated driving functions, these sensors will be one of the sources of information to maneuver the car in the center of the traffic lane. However, as demonstrated in previous chapter, there are various situations in which this sensor technology might fail: adverse weather and glare by oncoming vehicle or rising and setting sun. This cannot be solved by means of camera sensors alone, especially since this is not a measurement process from a physical point of view. A particularly well-suited sensor for this application is a Near-Infra Red (NIR) laser scanner LiDAR system. LiDAR sensors for ADAS, have shown promising results for road marking or lane detection in earlier research (Park, Reed & Sayer, 2019).

LiDAR sends out light pulses, and measures the time taken for them to return. It is an active light source, and, unlike a camera, it does not depend on strong natural lighting. In order to provide road marking detection capability, the LiDAR unit needs not only to detect an external object (road marking) but also to detect the target's degree of reflectance, measuring reflectance intensity (Marr, Benjamin & Zhang, 2020). This is a particularly important circumstance for the development of safety critical technology.

In the following graphic, the potential in detecting the road markings is illustrated by means of a measurement of reflectance intensities on the HTW (University of Applied Sciences Dresden- Prof. Dr Trautmann) test site. The LiDAR set up in Figure 9 was used to scan for 2 different road markings, the ones on the sides with (RI 1,9 and 2,4) on the sides; conventional paint with RI 1.5 in the center. The detected reflectance is shown 3 colours.

Two LiDAR ssystems are used, scanning for the marking and try to locate them as far as possible away from the sensors (= look ahead distance). Each laser channel covers a certain distance (dotted black lines on the graph). A strongly returned signal (red, blue or green) in contrast to the backscatter signal of the road (black signal dots) confirms that the marking can still be detected.

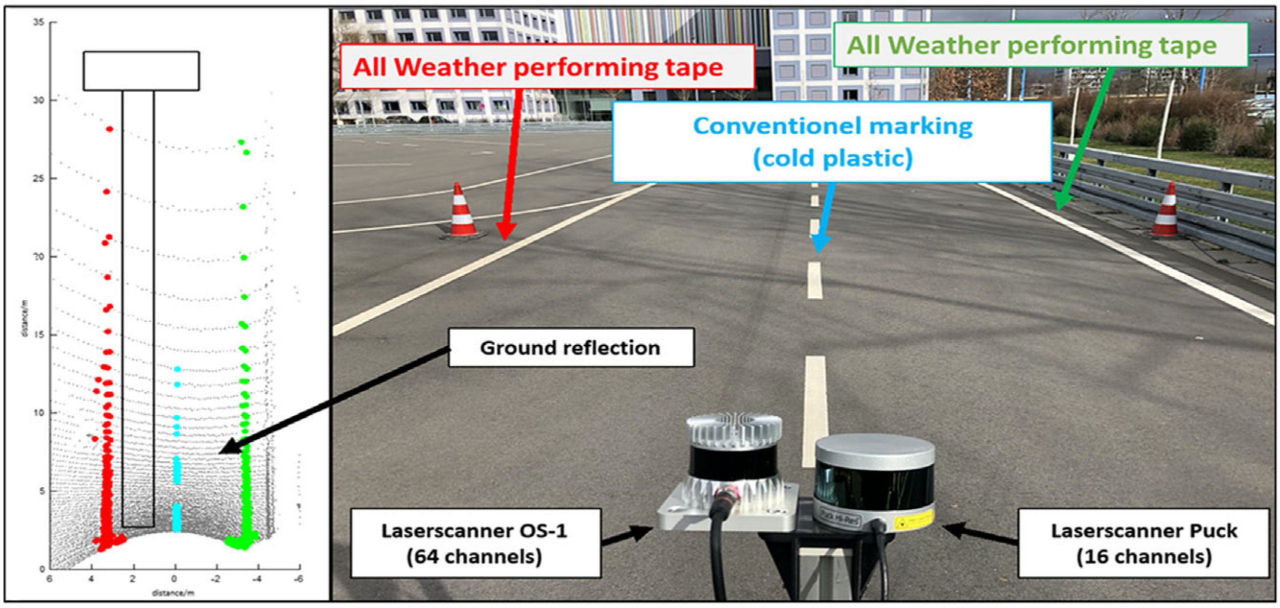


Figure 9: LiDAR Retroreflection intensities of different road markings

Looking at the intensities of the signals, there are clear differences between the 3 markings. it shows that higher retro-reflectivity leads to significantly higher backscatter intensities and thus to much better detection of the marking further away gaining visibility distance on higher performing preformed tape compared to the conventional markings.

Furthermore, a LiDAR test to compare the two different types of road markings in dry and immerged condition was conducted (see results in Figure10). Same as for visual light, glass beads with R.I. 1,7 only reflect the N-IR light when dry, while road markings containing both R.I. 1,9 and RI 2,4 beads will return LiDAR N-IR light in both dry and wet conditions.

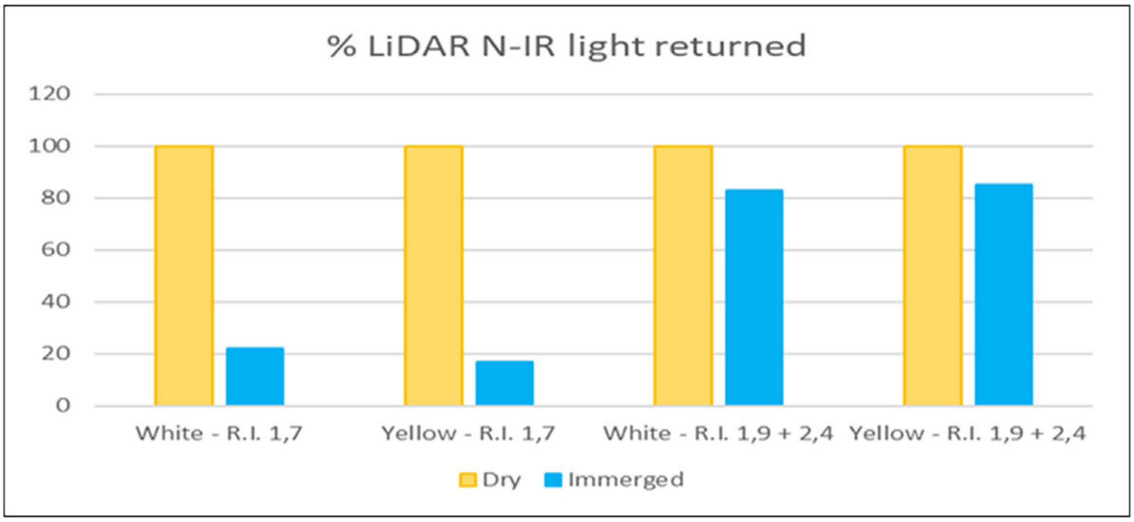


Figure 10: Comparing markings with different refractive index glass beads in relation to N-IR laser light return

This indicates that N-IR light with frequencies just outside the visual light spectrum (900 to 1000 nm) shows similar behaviour as visible light. As a LiDAR emits its own N-IR light during day and night, the detection of road marking highly depends on the presence of glass beads.

5. CONCLUSIONS

Rainvision Project conclusions (human): Driver's attitude and behaviour changed as the visibility of the road marking improve, they were more confident, stress was reduced and they saw road as well arranged with better visibility, the biggest changes were seen during wet and rainy condition. The improved visibility of markings during rain and dark weather does not encourage the driver to drive at excessive speeds. All drivers still drive slower and more careful than in dry conditions. The highest positive impact by the good visibility offered by a marking during night wet or rainy conditions has been noticed with oolder drivers who show more confidence and reduce the gap in speed between younger drivers. A smaller difference in speed, especially during adverse weather and low visibility conditions, may lead to less conflicts and reduce the risk of crashes.

The VEDECOM project: The ADAS camera system can detect most of the road markings correctly during the day, even old paint. During nighttime, all markings with reflective properties can also be seen. It was found that under wet and rainy conditions that product with RI 1,9 +2,4 was the only product detected showing higher contrast. The special use case of glaring sun showed that, in specific configurations (dry, sun in front), the black masking tape may become visible through its gloss level and is detected as a real road marking, meaning a "false positive", most possibly leading to confusing information to the driver. This found limitation may lead to accidents.

LiDAR performance is only based on the backscatter intensity of the near-IR laser signal emitted by the LiDAR system, this means that for both day and night situations, only the glass bead quantity and quality will have impact on a better detection of the road marking.

High retroreflectivity in wet and rain leads to significantly higher backscatter intensities and thus to much better increase detection of the marking with the LiDAR system.

It was determined that the use of better performing bead (RI. >1,7) on the road marking can result in improved detetion by human as well as machine vision and this should be possible during night or day under different weather condition. Lidar was found to be the promising future technology for AV but all weather performing road marking would have to be used.

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