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INTELLIGENT ROAD LIGHTING CONTROL IN VARYING WEATHER CONDITIONS

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This paper focuses on intelligent road lighting control and on road lighting measurements and calculations. Road lighting measurements are made to study the definition of appropriate road surface luminance levels during different weather conditions. The dimensioning and investigation of different weather conditions and their effects on drivers' visibility offer new ways to optimize intelligent road lighting control. With an effective road lighting control system electricity can be saved without adversely affecting either the safety of driving or the quality of road lighting [1, 2].

1. INTRODUCTION

Road lighting is a practical tool in ensuring good visibility conditions in night-time driving. So far, road surface luminance have been based on standardized lighting classes, using certain static luminance levels in certain road types [3]. In practice, however, luminance levels of road surfaces are usually very dynamic and depend to large extent on many external factors such as weather conditions, ambient brightness, external buildings etc. For example in Finland during wintertime the intensity of road lighting is often excessive in relationship to the standard requirements because of the snow [3]. Recent increases in the cost of electrical energy have caused actions to minimize energy costs. Activities of technological research and development have been carried out in order to find solutions and coherent guidelines for intelligent road lighting control.

2. WEATHER MEASUREMENTS

2.1 Measurement method and equipment

Road lighting calculations and measurements in Europe follow the European standard EN 13201-3 [4]. In this work road lighting measurements and calculations were done according to the standard, except the observer locations. All measurements were made using the luminance photometer ProMetric 1400 and the Radiant Imaging ProMetric and Road LumiMeter computer programmes.

The ProMetric 1400 luminance photometer is a computer controlled CCD-based imaging photometer, which is applicable for luminance measurements and analysis in indoor and outdoor lighting. The photometer consists of a 2-stage Peltier cooled 14-bit CCD camera, a photopic filter and a choice of lenses. The photometer is controlled by Radiant Imaging ProMetric software. The system accuracy for luminance measurements is ± 3 % [3].

2.2 Results of the weather measurements

In this work five different pilot locations were used for road luminance measurements. The pilot locations were measured using exactly the same method during different seasons and weather conditions (dry, wet, snowy). The parameters of the pilot locations are presented in Table 1. The measurements were made in January, March, June and October between 11 pm and 2 am.

Results of the road luminance measurements on two road sections VT3 (MH) and Leppälinnunrinne are presented in Figs. 1 and 2. The results are shown

Table 1

Pilot locations of luminance measurements in different weather conditions.

Pilot location	Lamp type	Road type	Weather conditions
VT3	MH	Highway	dry, slightly snowy, wet
VT3	HPS	Highway	dry, slightly snowy, wet
Jakokunnantie	HPS	Local street	dry, snowy, wet
Leppälinnunrinne	HPS	Local street	dry, very snowy, wet
Ring Road III	HPS	Highway	dry, snowy, foggy, wet

in isocolor presentations. Colors and palettes show the luminance distribution. For each measurement, the average luminance, overall uniformity and longitudinal uniformities were calculated. Average luminances and overall uniformities were calculated for the entire carriageway, whereas longitudinal luminance uniformities were calculated for each lane separately.

Fig. 1b with slightly snowy road surface represents quite ordinary winter driving conditions in Finland. On the major roads there is usually not much snow because of salting and snow clearance. However, road surroundings are covered with snow which increases the overall brightness of night-time driving conditions. As shown in Figs. 1a and 1b, the average luminance of slightly snowy surface is 50 % higher compared to the dry surface although road surface is almost clear of snow. And the more snow there is, the brighter it gets. Thus with road lighting that is dynamically adjusted to the prevailing conditions, there is potential to achieve considerable energy savings without adversely affecting the quality of lighting.

The road luminance measurements on road section Leppälinnunrinne focused on more extreme weather conditions (Fig.2). The measured average luminance of very snowy road surface was 4.25 cd/m^2 which is four times higher than the average luminance on dry road surface (1.15 cd/m^2).

Road surface luminances in wet conditions were several times higher than in normal dry conditions (Figs. 1c and 2c) [6]. The biggest problem in wet conditions is the specular reflection factor towards the observer which might result in causing discomfort glare [7, 8]. Together with the cumulative effect of oncoming vehicle headlights reflecting from the wet road surface the glare effect becomes even more problematic. It is also very difficult to upkeep good quality of lighting on wet road surface because of its dynamic characteristics. The road surface luminances are very unstable because the surface is

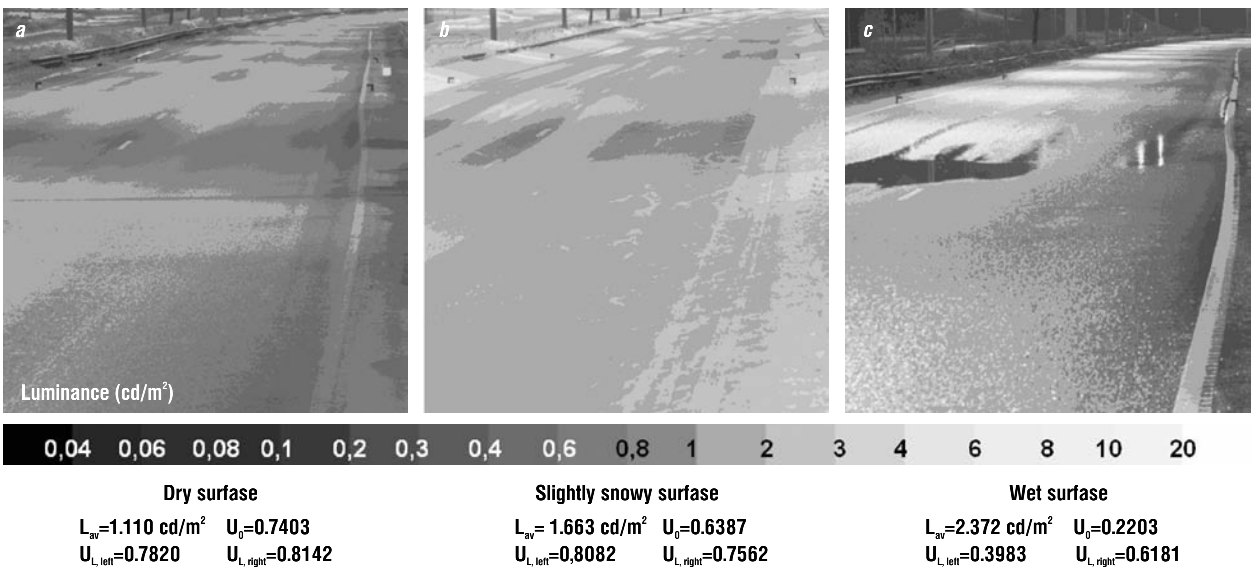

Fig. 1. Luminance distributions of the pilot location VT3. The road section is lit with 150 W MH lamps. Average luminance L_{av}, overall luminance uniformity U_o and longitudinal luminance uniformities for the left, $U_{L,left}$, and right, $U_{L,right}$, lanes

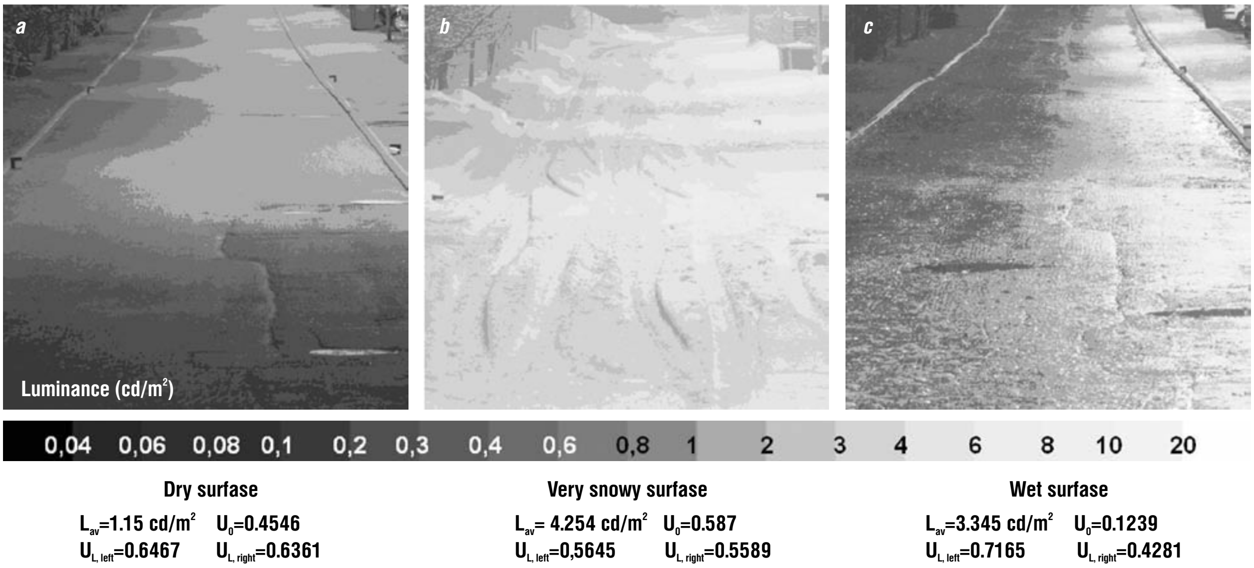

Fig. 2. Luminance distributions of Leppälinnunrinne in different weather conditions. The road is lit with HPS lamps

usually either becoming wetter or else it is drying. Luminance uniformities are poor and, furthermore, as shown in Fig.1c, reflections from ponds can disturb drivers' visibility. However, the average luminances are usually quite high and with an efficient road lighting control system based on real-time measurements there is perhaps a possibility to benefit from high luminance levels.

3. OPTIMIZATION OF AN INTELLIGENT ROAD LIGHTING CONTROL SYSTEM

To be able to save electricity, and at the same time upkeep the required lighting quality level, dynamic lighting is required. An intelligent lighting control system is the advanced solution to realize dynamic lighting. An intelligent road lighting control system is defined here as a modern lighting control system, which can automatically collect and analyze system information and realize the optimum lighting control effect by changing lamp light output according to certain control parameters, e.g. traffic volumes, weather conditions, road surface luminance and so on. At the moment, there exists no guideline or standard specifying which control parameters should be used for an intelligent road lighting control system.

According to weather measurement results, it is reasonable to utilize road surface luminance as one of the control parameters for an intelligent road lighting control system. To be able to utilize road surface luminance as control parameter, careful considerations should be taken considering the placement of the luminance meter and the measurement area on the road. In practice, this means that the location of the luminance meter and the measurement area on

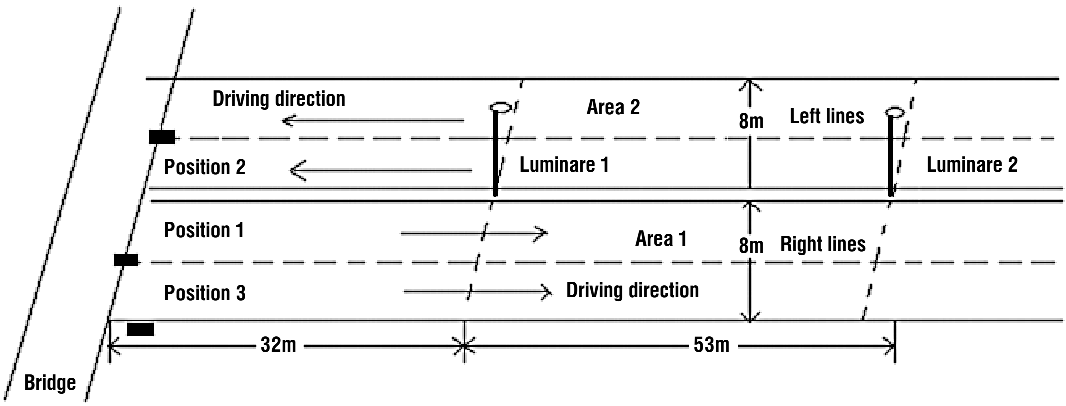

Fig. 3. Illustration of measuring positions, observed areas, and driving directions on VT1

the road has to be selected and calculated specifically for different cases.

In theory, the luminance meter of the lighting control system should be installed according to the standard so that the observation point is placed 1.5 m above the road surface and luminance measurements are taken with the viewing angle between 0.5° and 1.5°. In practice, however, the measurements by the luminance meter are affected by traffic flows on the road. When the luminance meter is installed at standardized viewing height, the effects of car headlights/backlights are significant in increasing the road surface luminance values. Consequently, the luminance differences in varying weather conditions may not be detected by the intelligent control system, thus the potential energy savings cannot be achieved in some cases. So in practice, installing the luminance meter at the standardized driver's viewing height and driver's observation angle may not be the most functional solution.

The Lighting Laboratory of Helsinki University of Technology has been active in development and optimization of intelligent road lighting control systems. Activities have been carried out to find a solution as to how to utilize the results of luminance measurements in varying weather conditions. Also, luminance measurements have been made to optimize the suitable position of a luminance meter in intelligent road lighting control installation.

A series of measurements were taken in order to find out an optimal solution for the placement of the luminance meter in the intelligent road lighting control system. The measurements were taken on a four-lane road, VT1 between Kolmperä and Lohjanharju, which is one of the main highways in southern Finland. VT1 consists of two carriageways separated by a central reservation. Each carriageway consists of two traffic lanes and the width of each carriageway is 8 m. VT1 is lit with high pressure sodium lamps and the luminaire spacing is 53 m. A CCD-based imaging luminance meter, LMK Mobile Advanced, was used in the measurements and the results were analysed by computer programme LMK 2000.

The measurements were divided into two parts. Fig. 3 represents the measurement set-up and measuring positions. The aim of the first part was to investigate how car head/rear lights affect road surface luminance measurements. The luminance meter was placed in Position 1 in the middle of the right carriageway (right lanes) on the bridge. Position 2 was also located on the bridge, but in the middle of the left carriageway (left lanes). The bridge is 6 m high and located at a distance of 32 m from the observed area. The measurement area was located between luminaire 1 and luminaire 2 as illustrated in Fig. 3.The road surface luminances ware measured in both positions for each driving direction with and without a car so that the effects of car headlights and rear lights could be investigated. The measurement results are shown in Fig. 4 and Table 2.

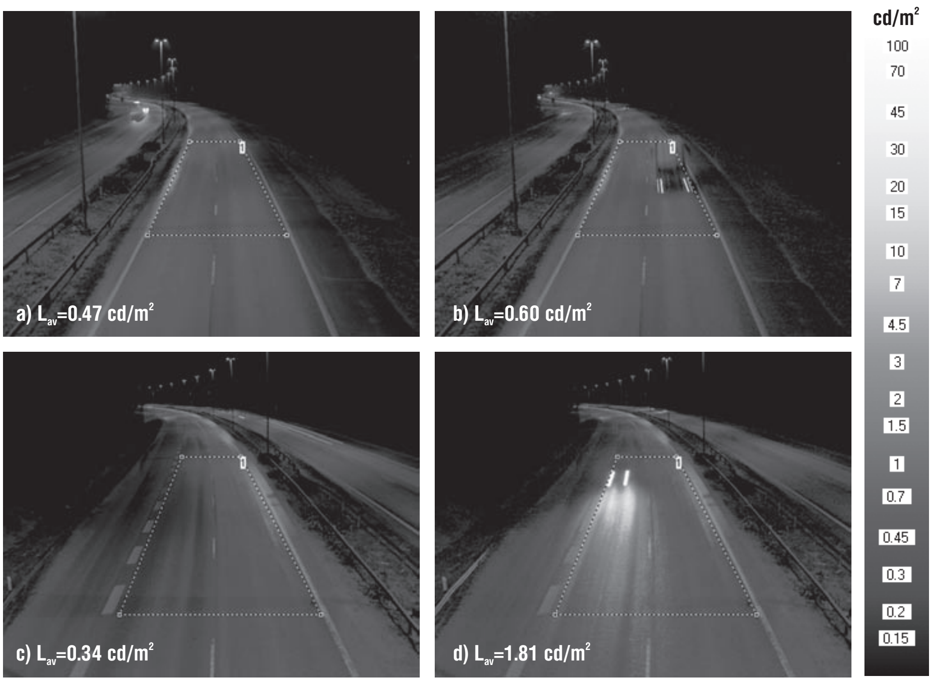

Fig. 4. Luminance measurement results on VT1.
a) right carriageway with no cars,
b) right carriageway with the luminance meter oriented to the driving direction of a car,
c) left carriageway with no cars,
d) left carriageway with luminance meter oriented opposite to the driving direction of a car. L_{av} is the average luminance of the defined road surface area

Table 2

Luminance measurement results on VT1

Two directions	L_{av} (cd/m^2) No cars	L_{av} (cd/m^2) one car on the road	Increase in L_{av} by car rear/head lights
Right lanes	0.47	0.60	28%
Left lanes	0.34	1.81	432%

Even though the measurements were not made from the driver's position, the measurement results however indicate how significantly the car rear lights and headlights affect the road surface luminance values. The luminance measurement results show that if the luminance meter is placed towards the direction of incoming traffic. the average road surface luminance in some cases can be more than four times higher compared to the road surface without the effect of traffic lights. If the luminance meter is placed towards the direction of outgoing traffic effects of car lights are substantially lower (28 %).

In practical applications of luminance monitoring control parameter value for the road surface luminance is the average value over a certain time period. Thus the effects of car rear/head lights are smaller than those presented in the measurements. Still it is recommended that the luminance meter is placed on the facing right in order to minimize the disturbance of traffic flow.

Another possible solution is to utilize road surface luminances as a minor parameter when traffic flow is high and to use the luminance levels as a major parameter when traffic flow is low so that the effects of traffic can be minimized.

The aim of the second part of the measurement was to study the effects of measuring height on road surface luminance under different weather conditions. The measurements were made in dry wet and icy conditions. The luminance meter was placed in Position 1 in the middle of the right carriageway on the bridge 7.5 m above the road surface. The same

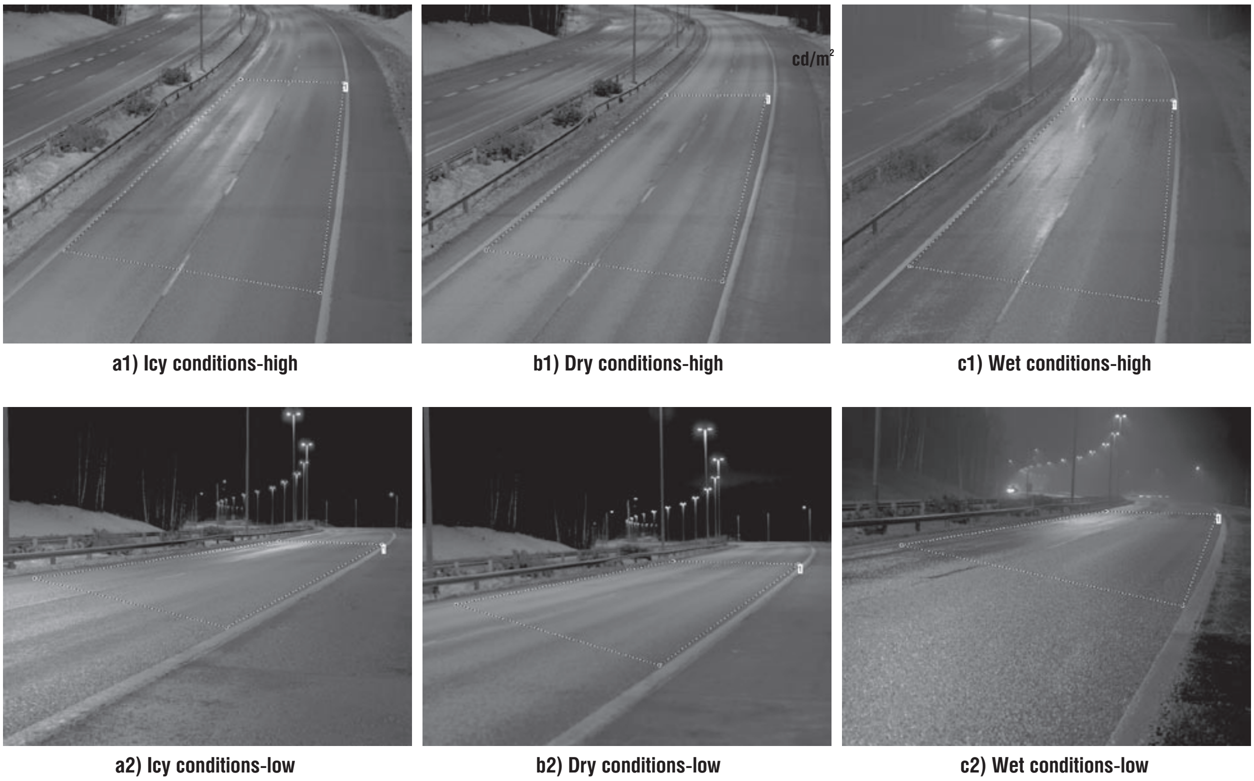

Fig. 5. Road surface luminance measurements at different measuring heights in different weather conditions. a1) icy conditions at high measuring height, a2) icy conditions at low measuring height, b1) dry conditions at high measuring height, b2) dry conditions at low measuring height, c1) wet conditions at high measuring height, c2) wet conditions at low measuring height

Table 3

Comparison of road surface luminance at different measuring heights in different weather conditions

Weather conditions	Icy	Dry	Wet
L_{high}/L_{low}	1.46	1.14	0.69

measurements were also made from Position 3. Position 3 was located on the side of the road at observation height of 1.5 m. The measurement results are shown in Fig. 5 and Table 3.

Note: L_{high} is the average luminance of the observed area at high measuring height. L_{low} is the average luminance of the observed area at low measuring height.

The luminance measurement results show that when the road surface is icy or wet. different measuring heights have a significant effect on the road surface luminance. At the same time when the road surface is dry. the effect of the measuring height is much smaller than in icy and wet conditions.

In an intelligent road lighting control system the light distribution of the measuring area should represent the general light distribution on the road. It is also important that the measurement area on the road is straight.

4. CONCLUSIONS

This work focused on optimization of intelligent road lighting control by developing possible solutions in utilizing the road surface luminance as the control parameter for intelligent road lighting control system. Road luminance measurements were done to study the effects of different weather conditions on road luminance distributions.

Results of the road luminance measurements in different weather conditions show that by taking weather effects on road luminance into account. there is potential to achieve considerable energy savings. Luminance of snowy road surfaces can be multiple times higher than in dry conditions. And even if there is a minor amount of snow and snow clearance is done, luminance levels are still about (40-100) % higher compared to conditions without any snow. Also the snow on the road to some extent affects the luminance uniformities of road surfaces. Further in some situations snowy and especially icy road surface illuminated by the headlamps of an oncoming vehicle can cause discomfort and disability glare and reduce driver visibility conditions.

In wet conditions the luminance distributions of road surfaces change significantly compared to the normal dry conditions. Road surface areas with specular refection towards the observation point become very bright and may cause discomfort glare. On the other hand, the luminance of the darker areas of road surface decrease. This results in lower luminance uniformities and in worsened driver visibility conditions. However, average luminances of wet road surfaces are usually much higher compared to the dry conditions.

To be able to take into account and benefit from the prevailing weather conditions, an intelligent road lighting control based on real-time measurements of luminance is needed. The luminance measurements in different weather conditions so far have been promising and in order to efficiently take advantage of the varying weather conditions. there is need to develop and investigate the possibilities of intelligent road lighting control.

The weather measurement results indicate that it is reasonable to use road surface luminance as one of the control parameters for intelligent road lighting control. However, although the weather measurements show the great luminance differences in varying weather conditions in real applications the intelligent road lighting control system may not detect the differences due to the effects of traffic flows. In intelligent road lighting, the sitting of the luminance meter should be considered carefully. since different positions of the meter result in varying road surface luminance results. In practice, this usually means a compromised position where the disturbances of traffic can be minimized.

The luminance measurements presented in this work do not represent any specified standard conditions of snowy and wet road surfaces. However, they do indicate remarkable changes which these conditions can have on the luminance distributions of road lighting.

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