Liping Guo, Marjukka Eloholma, and Liisa Halonen. 2007. Luminance monitoring and optimization of luminance metering in intelligent road lighting control systems. Ingineria Iluminatului, volume 9, pages 24-40.

LUMINANCE MONITORING AND OPTIMIZATION OF LUMINANCE METERING IN INTELLIGENT ROAD LIGHTING CONTROL SYSTEMS

Liping GUO, Marjukka ELOHOLMA, Liisa HALONEN
HUT-Helsinki University of Technology, Lighting Laboratory

For energy saving reasons, intelligent road lighting control systems are increasingly used and road surface luminance is one possible input parameter. In this paper the current status of luminance monitoring is reviewed giving emphasis on road surface luminance monitoring. In practice many factors may affect road surface luminance monitoring, e.g., different road surface properties under varying weather conditions, orientation of luminance meters, different measuring heights and distances, disturbances of road profile and vehicles on the road. A series of road surface luminance measurements were conducted and the measuring results were analysed in order to find out the optimal placement of luminance meters. The paper ends up with recommendations on luminance metering for intelligent road lighting control systems.

1. Introduction

Intelligent lighting control systems are increasingly applied not only in building automation, but also in outdoor applications such as road and tunnel lighting. The essential idea of intelligent lighting control is that the light levels can be dimmed or switched on/off when needed and meanwhile certain amount of light levels should be maintained. By this way energy consumption can be reduced without negative effects on the provided light quality. The monitoring of light levels then becomes a key issue in intelligent lighting control.

In indoor lighting, occupancy sensors, and light sensors are increasingly employed in office lighting. Light sensors are illumination monitoring devices in the sense that they measure the illuminance of the monitored area [1]. Daylight sensors are also used to monitor illuminance provided by daylight in order to optimize the use of electrical indoor lighting [1]. In tunnel lighting, luminance metering is needed for monitoring the tunnel entrance luminance [2].

For energy saving reasons, intelligent road lighting control systems are increasingly used and road surface luminance is considered as one of the possible control parameters. Monitoring the road surface luminance is very difficult to realize in practice because many factors may affect the luminance measuring, e.g., different road surface properties under varying weather conditions, disturbances of road profile and vehicles on the road.

In this paper, the current status of luminance monitoring is reviewed giving emphasis on road surface luminance monitoring. A series of road surface luminance measurements were conducted and the measuring results were analysed in order to find out the optimal placement for luminance meters. The paper ends up with recommendations on luminance metering for intelligent road lighting control systems.

2. Luminance monitoring and intelligent road lighting control systems

In indoor lighting illuminance monitoring is commonly used because of the need to know how much light can reach the tasks. Light sensors are illuminance monitoring devices employed in indoor lighting to switch on/off or dim the light [1]. The placing of those sensors is probably the most critical phase of lighting control in the sense that this is where most mistakes are made [1]. It is important to ensure that the sensors are oriented towards the working area to be illuminated and that no direct light from the luminaires under control or from the windows reaches the sensor [1]. Some light sensors are installed to monitor outside daylight in order to optimize the use of inside artificial lighting. To be effective, multiple sensors may be needed in order to detect the direction of lighting.

An example where luminance monitoring is needed is in tunnel lighting control. The access zone luminance of tunnel varies with changes in daylight conditions. During the day, the luminance levels in the threshold and transition zones need to be constant percentages of the luminance in the access zone [2]. Therefore, for adequate light control the access zone luminance must be monitored continuously [3]. The most practical solution is to place a luminance meter at the stopping distance, aimed and centred at the tunnel portal [2]. For maintenance reasons, the luminance meter should be mounted between 2 m and 5 m height above the pavement or hard shoulder on the near side of the road [2], [3]. It is also recommended to measure the interior luminance with another luminance meter [3]. Again, it is not possible to measure the luminance from the position of the driver's eye in practice. For practical reasons the mounting height of the luminance meter has to be greater than that of the highest truck, i.e., above 4.5 m. Therefore the measured value is different from the luminance seen by the driver [3].

For energy saving reasons, intelligent road lighting control systems are increasingly used. Two essential missions of an intelligent road lighting control system are monitoring and control. Monitoring lamp status can reduce the maintenance costs by reduced routine inspection and well planned lamp group replacement. Control of lamps can lead to energy savings by lowering the lamp power when less light is enough for traffic according to several control parameters, e.g, traffic amount, road surface luminance, road weather conditions, and so on. An intelligent road lighting control system consists of control centre (host computers), remote terminal units (also called central controllers), light control units (also called local controllers), ballasts and lamps [4].

The control centre is normally composed of computers and management software. The main functions of the control centre are collecting and estimating the information of lamps, making decisions according to control parameters, and saving the operation data. Remote terminal units are installed in the control cabinets of the road lighting installations. With the employment of microprocessor, remote terminal units can collect field information from light control units and send the information to the control center, receive the commands from the control center and transmit them to light control units. Light control units receive commands from remote terminal unit and execute the command, and transmit the status information of lamps to the remote terminal unit. Figure 1 illustrates the basic diagram of an intelligent road lighting control system.

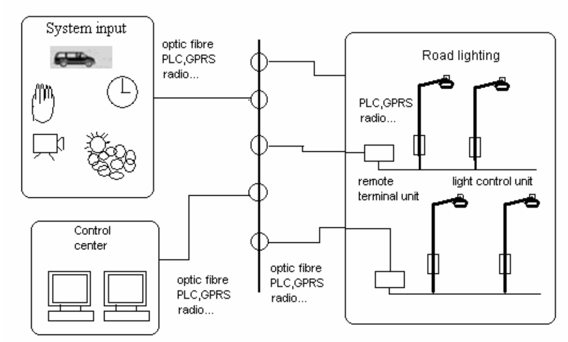


Figure 1 Basic diagram of an intelligent road lighting control system

In the existing installations of intelligent road lighting control systems, traffic amount is the most commonly used control parameter, because the initial motivation to develop intelligent road lighting control system is to decrease the light levels when traffic amount is low so that energy can be saved especially at midnight [4]. At the same time, energy savings should be achieved without decreasing traffic safety. Therefore, other control parameters should also be considered in order to keep lighting quality and explore more potential for energy savings. Road surface luminance is one possible control parameter [5]. However, monitoring road surface luminance is very difficult to realize in practice. Road surfaces luminance levels in road lighting are rather low compared to tunnel access luminances and many factors may significantly affect the road surface luminance measuring, e.g., varying road surface properties under different weather conditions, disturbances of road profile, vehicles on the road and different placement of the luminance meter. Ideally the luminance meter should be mounted at 1.5 m height, in the middle of lane to be consistent with the driver's view of luminances. In practice, it is not realistic to place the luminance meter at this height because the luminance meter will get dirty very quickly, be exposed to vandalism, and heavy snow may block the view of luminance meter. Then it is crucial to find an optimal position for luminance meters so that luminance measurements are reliable and the maintenance of luminance meter is easy and economic. Currently, luminance meters are in practice mounted at 4 to 6 m height attached to a light pole, a bridge or a separate pole. So far, there are no guidelines or instructions that specify where and what kind of luminance meter should be used to monitor the road surface luminance in an intelligent road lighting control system.

3. CCD-based imaging luminance meter and spot luminance meter

At the moment, both spot luminance meters and imaging luminance photometers are used in luminance measurements. Spot meters have been utilized in luminance measurement for over 50 years [6]. An imaging photometer is essentially a CCD (charge coupled device)-based camera connected to computer and it is increasingly applied in laboratory and field lighting measurements. Due to the novelty of the intelligent road lighting control system installations there are no luminance meters designed particularly for luminance monitoring in these systems yet. In some intelligent road lighting control systems, spot luminance meters designed for tunnel lighting control are applied for road luminance monitoring. Generally, luminance meters for tunnel applications measure the average luminance within a cone with a measuring angle of 20^{o}, and have an output of 4-20 mA DC for a luminance range 0-L cd/m^2 [7], [8]. *L* is chosen by users when ordering the photometer. A common value of '*L*' is 6500 cd/m^2 for tunnel applications. The measuring angle can also be changed according to users' demands.

Intelligent road lighting control systems mainly work during dawn, dusk and night at low light levels. Thus road surface luminance values are actually in a small range, which requires high sensitivity of the luminance meters at low light levels. There are spot luminance meters designed for tunnel lighting with luminance range of 0-32 cd/m^2, and an output of 4-20 mA DC which are used for luminance monitoring in intelligent road lighting control systems. But the observed area can not be selected freely. Once the installation height is set, the maximum measuring area on road surface is determined and the measuring area is an ellipse. The luminance meter averages the luminance values from the ellipsoid area so it does not respond to CEN road lighting measurement standard. At present, both CCD-based imaging photometers and tunnel spot photometers are expensive. With CCD-based photometers the measuring area can be freely selected from the captured images and detailed light distribution information can be achieved with the aid of image processing software. Those are the most important advantages of an imaging photometer over a spot luminance meter when considering road surface luminance monitoring.

4. Road surface luminance measurements

4.1 Orientation of luminance meters

The orientation of luminance meter was studied in order to find out the optimal orientation of luminance meters for road surface luminance monitoring. The measurements were conducted in a four-lane road, VT1 between Kolmperä and Lohjanharju, which is one of the busiest highways in southern Finland. The lighting installation is provided by high pressure sodium lamps with 53 m luminaire spacing. Central reservation separates the two driving directions. The width of each carriageway (two lanes) is 8 m.

A luminance meter can be oriented transversely or longitudinally in relation to the road. Supposing a spot meter with 20^0 viewing angle is mounted at 4 m height, 5.4 m far from the road edge and oriented transversely in VT1, the maximum measuring area on the road is an ellipse with semimajor axis a=4 m and semiminor axis b=1.7 m. Figure 2 illustrates the maximum measuring area for a spot meter with 20^0 viewing angle. Of course it is possible to get a larger measuring area, but in this case part of the ellipse will be outside the carriageway. If the spot meter is oriented longitudinally, and installed at 4 m height and 9 m far from the observed area, the maximum measuring area on the road surface is much larger, an ellipse with semimajor axis a=24 m and semiminor axis b=4 m. The maximum observed area on the road increases with mounting height and viewing angle. If the measuring area is small it may cause inaccuracy to monitored luminance values when there are road markings, snow, or faulty lamps in the measuring area. For a large measuring area, those will not cause big errors because the luminance is averaged over the whole area. With an imaging photometer, the measuring area can be selected from captured images so it is still possible to get the average luminance from a large area even though the meter is oriented transversely to the road. But when luminance meter is placed transversely, it does not correspond to luminances seen by the driver. This is emphasized with wet road surface due to the specular reflections from the road surface. Therefore, it is recommended to orient luminance meter longitudinally to the road, no matter if it is a spot luminance meter or an imaging photometer.

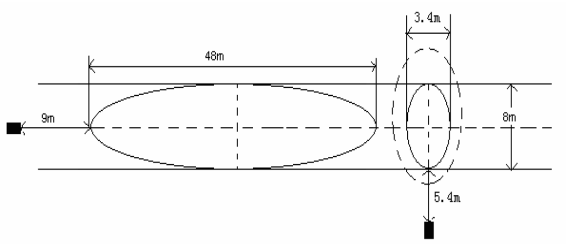


Figure 2 Measuring area of a spot meter with 20^0 viewing angle mounted at 4 m height in road VT1

In luminance monitoring, the effects of car head and rear lights should be considered if luminance meter is placed longitudinally. Road surface luminance measurements were conducted in VT1 in both driving directions to evaluate the effects of car headlights and rear lights on road surface luminances. The measurements were made using an imaging luminance meter LMK Mobile Advanced and analysed by computer program LMK 2000. The luminance meter was placed in the middle of each carriageway on a bridge over the road. The bridge is 6 m high and 32 m far from the observed areas which are between luminaire 1 and luminaire 2 as illustrated in Figure 3. The measurements were conducted at night time in November, 2006 when the road surface was dry. The road surface luminance for each driving direction was measured when there was a car/no cars so that the effects of car headlights and rear lights could be investigated. The measuring results are shown in Figure 4 and Table 1.

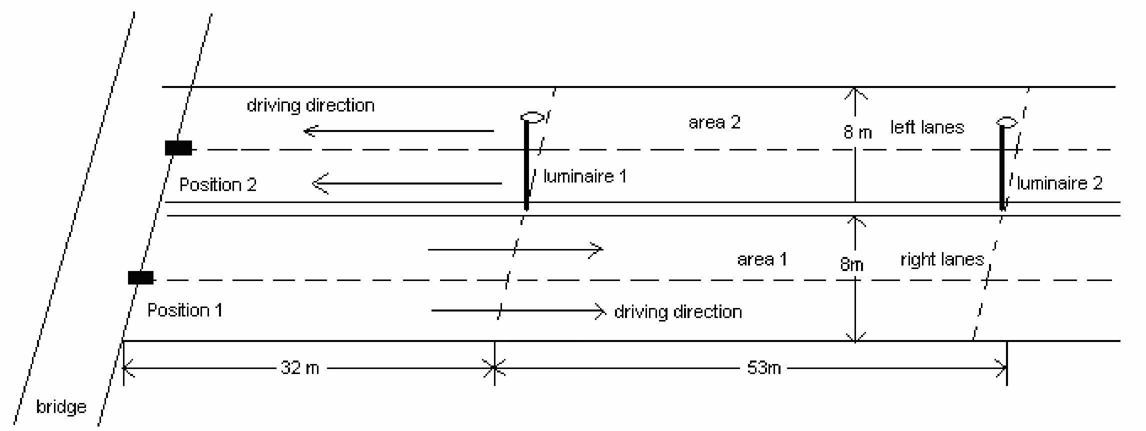


Figure 3 Illustration of measuring positions, observed areas, and driving directions in VT1

Table 1 Luminance measurement results in 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%

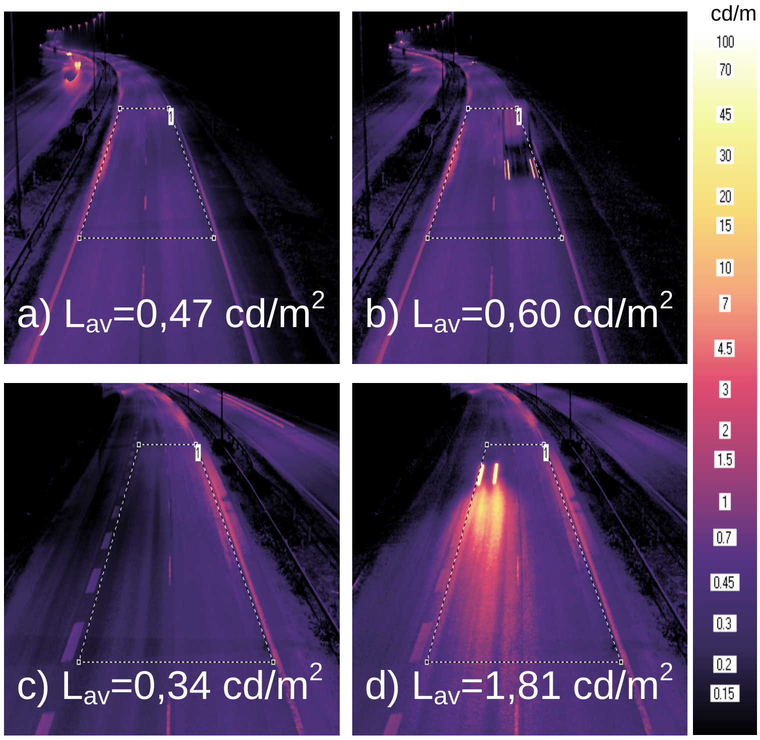


Figure 4 Luminance measurement results in VT1 a) the right lanes with no cars b) the right lanes with the luminance meter oriented to the driving direction of a car c) the left lanes with no cars d) the left lanes with luminance meter oriented opposite to the driving direction of a car. L_{av} is the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

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. Car rear lights increase the average luminance of the observed area by 28% and headlights by 432%. In luminance monitoring in practice, the luminance is the average value over time, so the effects of car rear/head lights are smaller than those in the measurements. But the effects of car headlights are still significant for road surface luminance monitoring and may cause malfunction of the road lighting control systems. Therefore, luminance meter for road surface luminance monitoring should be oriented to the driving direction of the road.

4.2 Measuring height, measuring distance and varying weather conditions

4.2.1 Experimental procedures

A series of measurements were conducted to investigate the effects of measuring height, measuring distance and different weather conditions on road luminance monitoring when the luminance meter is oriented longitudinally to the road and to the driving direction. The measurements were made using an imaging luminance photometer LMK Mobile Advanced and analyzed by the computer program LMK 2000.

The measurements were made in a local street with two lanes in Espoo, Finland. The installation is provided by high pressure sodium lamps with 32 m luminaire spacing. Figure 5 illustrates the installation and the measuring positions. The measuring area is between two adjacent luminaires. There are two parts of the measurements. One part of the measurements was made from the same side of the luminaires, 1 m from the road edge, and at different measuring heights and distances. A car with a lifting platform was used to attain measuring heights up to 5 m. The other part of the measurements was made at the driver's position according to the CEN standards, e.g., the observer position was at 1.5 m height and 60m from the measuring area [9], [10]. Three weather conditions (dry, snow and wet) were investigated.

The measurements were made during three nights in February and March 2007 between 22:00 and 23:30 o'clock. The weather conditions and different positions of the luminance meter are given in Table 2. Figure 6 illustrates the conditions under varying weather conditions.

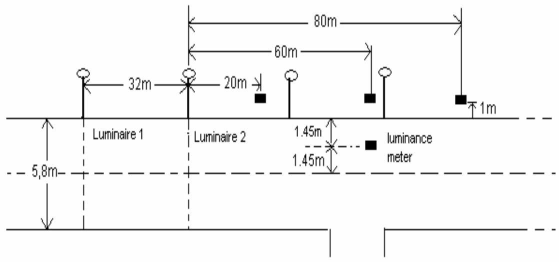


Figure 5 Illustration of installation and measuring position

Table 2 Weather conditions and different placement of luminance meter in the measurements.

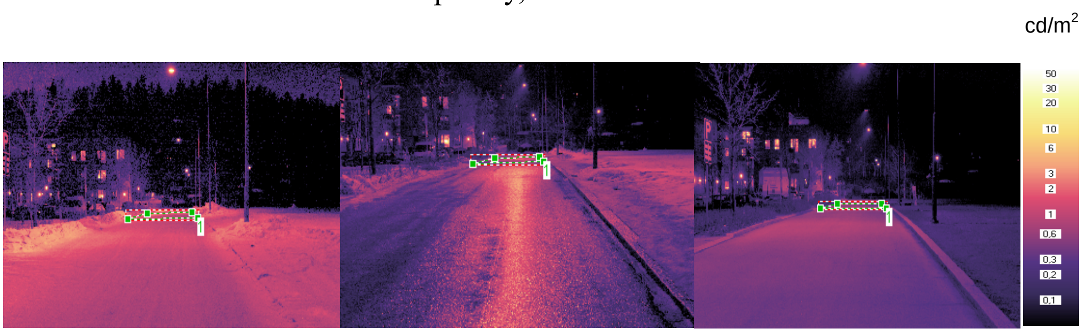
Date	12.02.2007	07.03.2007	27.03.2007
Time	22:00~23:30	22:00~23:30	22:00~23:30
Road surface	Snowy	wet	dry
Road Temperature (°C)	-9	1.7	3.5
Weather	Clear	Rain	Clear
Measuring distance (m)	20, 60, 80	20, 60	20, 60
Measuring height (m)	1.5, 3, 4, 5	1.5, 3, 4, 5	1.5, 3, 4, 5

a) b) c)

Figure 6 Photographs of the three road weather conditions, a) snow b) wet c) dry

4.2.2 Measurements from the driver's position

The luminance measurement results under varying weather conditions at the standard driver's position are shown in Figure 7 and Table 3. When the road surface was covered with snow, the luminance distribution was quite uniform and road surface luminance was substantially increased, e.g., for the same observed area 150% more than the average luminance under dry conditions. In intelligent road lighting control systems, the light output can be decreased when road surface or the adjacent areas are covered with snow, so that a constant light level on road surface is maintained. Consequently, great energy savings can be achieved. In this sense, the road surface luminance can be considered as one of control parameters in intelligent road lighting control systems. With wet road surface, the average luminance of the observed area was 36% more than that with dry road surface. However the overall uniformity under wet condition was quite poor compared to dry and snowy conditions. Thus in intelligent road lighting control information is also needed of the prevailing weather conditions, in order not to further decrease visibility by light level adjustment.



a) b) c)

Figure 7 Road surface luminances measured from 60 m distance, 1.5 m height, in the center of right lane under different road surface conditions, a) snow b) wet c) dry. The observed area is the road surface area between two adjacent luminaires.

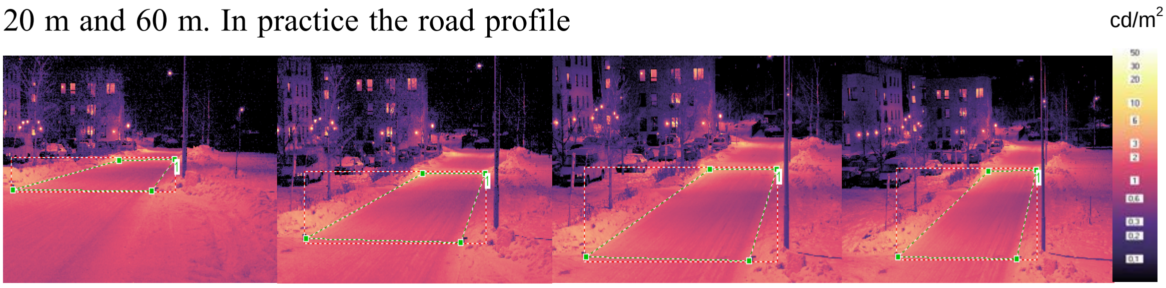
Table 3 Road surface luminance values measured at the driver's position

Road surface conditions	L_{av} (cd/m^2)	L_{av}: L_{av} (dry)	Overall uniformity $U_o = L_{min}/L_{av}$
Dry	0.56	100%	0.49
Snowy	1.40	250%	0.51
Wet	0.76	136%	0.33

Note: L_{av} is the average luminance of the defined area L_{av} (dry) is the average luminance under dry conditions, U_o is the overall uniformity defined as the ratio of the minimum luminance to the average luminance.

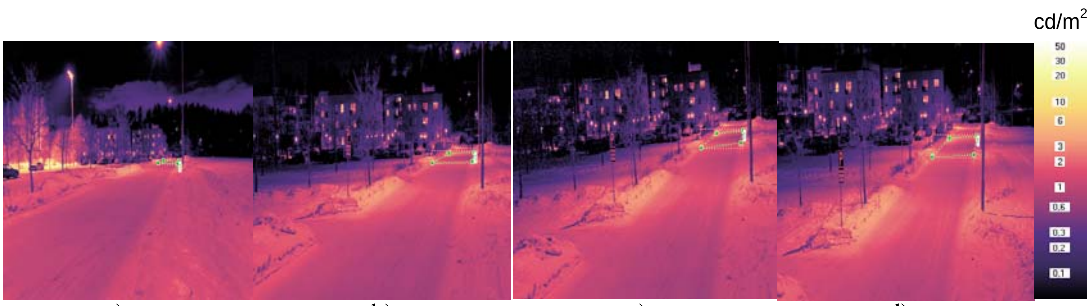
4.2.3 Road surface luminances in snowy conditions

When the road surface was covered with snow, the measurements were made from distances 20 m, 60 m and 80 m. It was possible to calculate the average luminance values of the observed road area measured at distances 20 m and 60 m, while it was not possible to get any average luminance values from the measurements at 80 m distance because the measuring area was too small to be detected by the photometer and the luminaire and traffic sign blocked the observed area. Therefore, when the road surface was wet and dry, the measurements were made only at two measuring distances, 20 m and 60 m. In practice the road profile is seldom completely flat and sometimes there are curves. So it is not recommended to place the luminance meter more than 60 m far from the measuring area. The measuring results with snowy road surface are shown in Figures 8-10 and Table 4. The differences in luminances between different placement of the luminance meter are small and very close to the average luminance measured at the driver's position, e.g., the luminance differences are in the range of -4% ~ 3% of the average luminance measured at the driver's position. The measuring height and measuring distance do not show significant effects on the measured luminances when the road surface is covered with snow.



a) b) c) d)

Figure 8 Road surface luminances measured at 20 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 9 Road surface luminances measured at 60 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

a) b) c) d)

Figure 10 Road surface luminances measured at 80 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

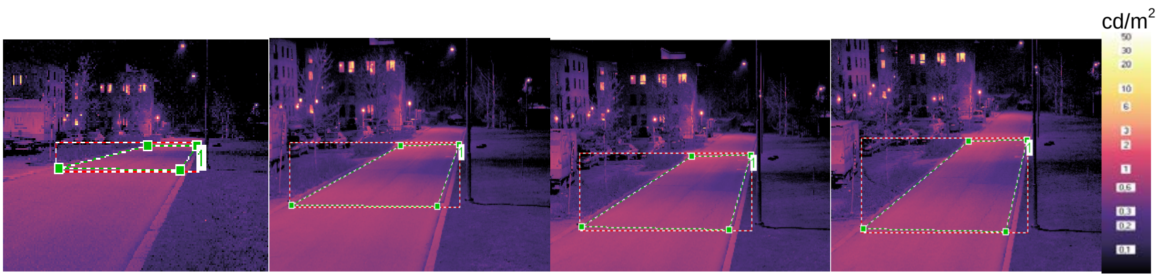
Table 4 Road surface luminance values in snowy conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	1.42	101%	1.37	98%	1.38	99%	1.44	103%
60	1.43	102%	1.40	100%	1.35	96%	1.42	101%

Note: L_{stan} is the average luminance measured from the driver's position in snowy conditions.

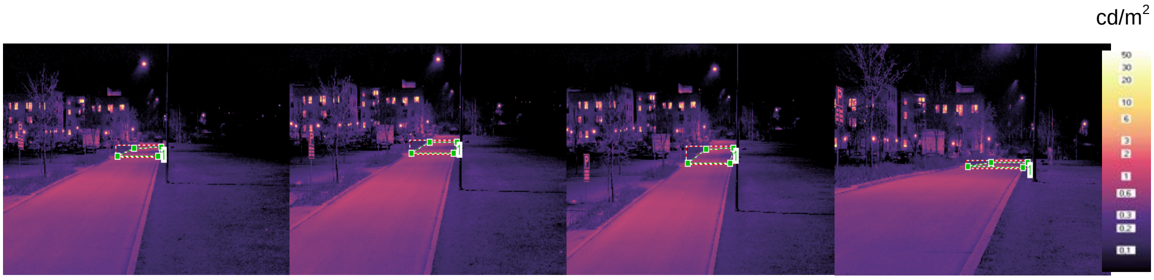
4.2.4 Road surface luminances in dry conditions

The luminance measurement results with dry road surface are shown in Figures 11-12 and Table 5. The average luminance values are close to each other at both measuring distances, 20 m and 60 m, and at all measuring heights, 1.5 m, 3 m, 4 m and 5 m. The luminance differences between different positions of the luminance meter are in the range of -2% ~ 9% of the average luminance measured at the driver's position. The measuring height or measuring distance does not show obvious effects on the measured luminances when road surface is dry.



a) b) c) d)

Figure 11 Road surface luminances measured at 20 m distance in dry conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 12 Road surface luminances measured at 60 m distance in dry conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

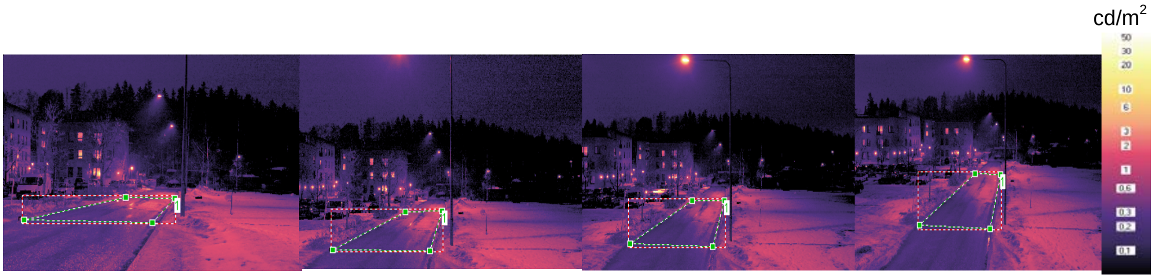
Table 5 Road surface luminance values in dry conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	0.56	100%	0.56	100%	0.55	98%	0.55	98%
60	0.57	102%	0.61	109%	0.58	104%	0.56	100%

Note: L_{stan} is the average luminance measured at the driver's position in dry conditions.

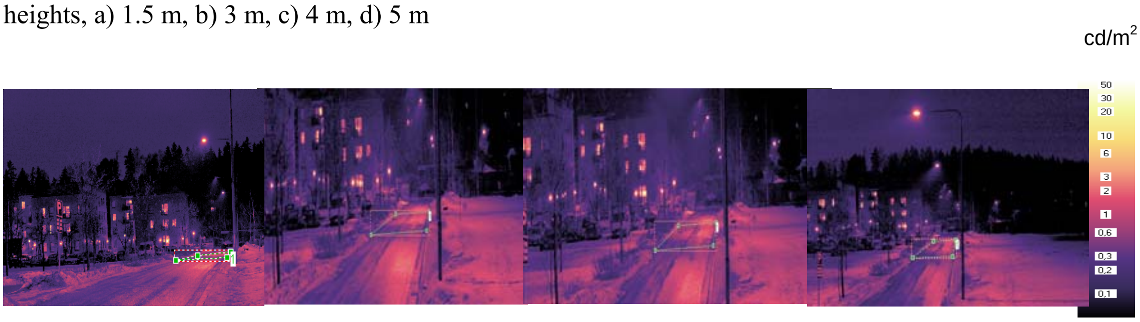
4.2.5 Road surface luminances in wet conditions

The luminance measurement results with wet road surface are shown in Figures 13-14 and Table 6. In these conditions the measuring height and distance have significant effects on the measured luminances. The luminance differences between different measuring heights and distances are in the range of -53%~-3% compared to the average luminance measured at the driver's position. It is quite difficult to find a general rule of how road surface luminances change with measuring height and measuring distance in wet conditions due to different road surface properties and various wetness conditions of road surface. In areas with specular reflections towards the observation point the luminances of the road surface increase substantially and form very bright areas. On the other hand, there are also darker areas which increase in size due to wetness. The road surface luminance measurements indicate remarkable changes caused by wetness to road surface luminances. Compared to the dry road surface the luminances in wet conditions can be either decreased or increased and thus no general rules can be given for using road surface luminance as input parameter for a road lighting control system in wet conditions.



a) b) c) d)

Figure 13 Road surface luminances measured at 20 m distance in wet conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 14 Road surface luminances measured at 60 m distance in wet conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

Table 6 Road surface luminance values in wet conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	0.59	78%	0.45	59%	0.36	47%	0.36	47%
60	0.67	88%	0.74	97%	0.72	95%	0.58	76%

Note: L_{stan} is the average luminance measured at the driver's position in wet conditions.

4.3. Discussion

The measurement results under varying weather conditions are summarized in Table 7 and the trendline of road surface average luminance is shown in Figure 15. When the road surface was covered with snow, the luminance values are substantially higher than those in dry and wet conditions. For an intelligent road lighting control system, this indicates the possibility to decrease the light levels so that energy saving can be achieved.

As listed in Table 7, the standard deviation of the average luminances when road surface was covered with snow is 0.03 cd/m^2, average value of the luminances is 1.40 cd/m^2, and the ratio of the standard deviation to the average luminance is 0.02. In dry conditions the ratio of the standard deviation to the average value is 0.03. So when the road surface is dry or covered with snow, different measuring distances and measuring heights do not introduce relevant variations on the measured road surface luminance values. While under wet conditions the standard deviation of the measuring results is 0.15 cd/m^2, which is much larger than that under dry and snowy conditions. And the ratio of the standard deviation to the average value is 0.27, which is much larger than those in dry and snow conditions. These differences indicate that in wet conditions luminance measuring is affected more significantly by the measuring height and measuring distance than in dry and snow conditions.

When the road surface is wet, the average luminance values change significantly with measuring height and measuring distance of the luminance meter. The average luminance values of wet road surface may be higher or lower than that of dry conditions depending on the placement of the luminance meter, the road surface properties and the wetness of road surface. Therefore road surface luminance is not a reliable control parameter in wet conditions. A practical solution is to exclude the road surface luminance information in wet conditions from the control parameters.

As discussed in chapter 4.1, when the luminance meter is oriented longitudinally to the road and to the driving direction of the lane, the effects of car rear lights are not significant. While when full of cars, road surface luminance can not be used as control parameter any more because it will be not possible to measure the real road surface luminance. In this case, other control parameters should be used, e.g. traffic amount and speed. More research work is needed to find out which other possible control parameters could be used in intelligent road lighting control.

Table 7 Average road surface luminance values in different weather conditions

Measuring height (m)	L_{av} (cd/m^2) Dry		L_{av} (cd/m^2) Wet		L_{av} (cd/m^2) Snow	
	Distance 20 m	Distance 60 m	Distance 20 m	Distance 60 m	Distance 20 m	Distance 60 m
1.5	0.56	0.57	0.59	0.67	1.42	1.43
3	0.56	0.61	0.45	0.74	1.37	1.40
4	0.55	0.58	0.36	0.72	1.38	1.35
5	0.55	0.56	0.36	0.58	1.44	1.42
σ (cd/m^2)	0.02		0.15		0.03	
L (cd/m^2)	0.57		0.56		1.40	
σ:L	0.03		0.27		0.02	

Note: σ is standard deviation. L is the average value of luminances measured at different measuring heights and measuring distances.

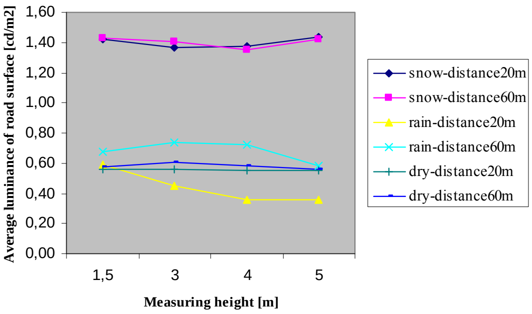


Figure 15 Average luminances measured at different heights (1.5 m, 3 m, 4 m, 5 m), distances (20 m, 60 m) and weather conditions (dry, wet, snow)

5. Conclusions

In intelligent road lighting control systems, road surface luminance is considered as one of the possible control parameters. Monitoring road surface luminance is then necessary and many factors should be considered in the optimization of luminance metering.

In practice, normally it is not possible to place the luminance meter at driver's position. In order to get larger observed area and simulate the driver's view, the luminance meter should be oriented longitudinally to the road. Meanwhile, the effects of car headlights are significant for road surface luminance monitoring whereas the car rear lights do not have obvious effects on the average luminance values of a large enough measuring area. So it is recommended to orient the luminance meter to the driving direction. For a spot luminance meter, the measured area increases with mounting height and viewing angle of the meter. For both spot meters and imaging photometers it is recommended to place the meter at ≥ 3 m height in order to keep the lens clean, prevent it from vandalism, and from blocking by obstacles on the road. Currently, only spot luminance meters designed for tunnel applications are used in intelligent road lighting control systems. In this case the observed area is an ellipse which is defined by the mounting height of the meter and the width of the road. With a CCD-based imaging photometer, the measuring area can be freely selected from the captured images and detailed light distribution information can be achieved with the aid of imaging processing software.

For luminance monitoring, it is not recommended to install the luminance meter far from the observed area, e.g., measuring distance should not be more than 60 m. As in practice the road profile is seldom completely flat and sometimes there are curves, it is quite difficult to measure the road surface if the luminance meter is far from the observed area.

When the road surface is covered with snow, the average luminance is substantially higher than that with dry and wet road surface. When road surface is dry or covered with snow, luminance values are not affected by the measuring distance or the measuring height. In wet conditions, on the other hand, road surface luminances vary with measuring heights and measuring distances of the luminance meter. In wet conditions, visibility is reduced but the road surface average luminance may be higher than that under dry conditions due to specular reflections. If the lamp dimming levels change with the average road surface luminance, the lamp will be dimmed down and visibility will be reduced further. In intelligent road lighting control systems, one practical solution is to exclude the luminance information of wet road surface from the input parameters in adjusting light levels.

References

1. Robert S. Simpson, *Lighting control technology and applications*, Chapter 14, Focus press 2003
2. CEN, *Lighting applications-tunnel lighting*, Ref. No. CR 14380:2003 E
3. CIE, *Guide for the lighting or road tunnels and underpasses*, CIE88, 2004
4. Guo Liping, Eloholma Mariukka, Halonen Liisa, Intelligent road lighting control systems-overview and case study. *International review of electrical engineering*, Vol. 2, No. 1, January-February, 2007.
5. Ekrias Aleksanteri, Guo Liping, Eloholma Mariukka, Halonen Liisa, Intelligent road lighting and effects of weather conditions on road luminances. Presented Poster for the 26th sesion of the CIE in Beijing, China, 4.7-11.7.2007.
6. J.B. De Boer, M. Cohu, A.B.De Graaff, B. Knudsen, D.A. Schreuder, *Public lighting*, Philips Technical library, 1967.
7. Specifications of Mayer TS-101 luminance photometer.
8. Specifications of Hagner tunnel entrance photometer TLS-420/S
9. EUROPEAN STANDARD EN 13201-3 *Road lighting – Part 3: Calculation of performance*, Publication 270-2003, Ref. No. EN 13201-3:2003 E.
10. EUROPEAN STANDARD EN 13201-2 *Road lighting – Part 2 Performance requirements*, Publication 269-2003, Ref. No. EN 13201-2:2003 E.

Liping GUO
M.Sc, Research scientist,
Lighting Laboratory,
Helsinki University of
Technology, Finland
Otakaari 5,
FI-02150 ESPOO,
Tel: +358-9-4514983
E-mail: lguo@cc.hut.fi

She got her Bachelor degree from Electrical Department in Shanghai Jiaotong University, China in 2000 and Master degree from Department of Electrical and Communication Engineering, Helsinki University of Technology, Finland in 2004. She is a research scientist in Lighting Laboratory, Helsinki University of Technology. Her research interests include lighting control, and road and street lighting.

Marjukka ELOHOLMA
D.Sc., Research scientist,
Lighting Laboratory,
Helsinki University of
Technology, Finland
Otakaari 5,
FI-02150 ESPOO
Tel: +358-9-4514981
marjukka.eloholma@tkk.fi

She earned her doctorate in illuminating engineering in 2005 from Helsinki University of Technology, Finland. She is the leader of the Traffic Lighting and Vision research group of Lighting Laboratory, Helsinki University of Technology. Her interest areas of research include road lighting and visibility at low light levels.

Liisa HALONEN
D.Sc., Professor,
Lighting Laboratory,
Helsinki University of
Technology, Finland
Otakaari 5,
FI-02150 ESPOO,
Tel: +358-9-4512418
E-mail:liisa.halonen@tkk.fi

She earned her doctorate in illuminating engineering in 1993 from Helsinki University of Technology, Finland. She is the head of the Lighting Laboratory of Helsinki University of Technology and is responsible for the education and research activities of the laboratory. Prof Liisa Halonen has several years of experience in national and international research projects. Currently she is the Operating Agent of IEA Annex 45 Energy-Efficient Electric Lighting for Buildings.

Received 12.08.2007