Modifying the concept of semi-cylindrical illuminance : further investigations on facial recognition

Patrick Rombauts

ABSTRACT

The theoretical concept of the semi-cylindrical illuminance itself is modified by vertically truncating the receiving surface of the upright half cylinder. This truncating is done in such a way to obtain maximum correlation between the "modified" semi-cylindrical illuminance and facial recognition. Herewith, the concept of "effective" light source and modelling of three-dimensional objects and faces is discussed too.

MODIFICATION DU CONCEPT DE L'ECLAIREMENT SEMI-CYLINDRIQUE : DE PLUS AMPLES INVESTIGATIONS SUR LA RECONNAISSANCE DU VISAGE

RESUME

Le concept théorique de l'éclairement semi-cylindrique a été modifié par un tronquage vertical de la surface convexe du semi-cylindre relevé. Ce tranchement a été fait de telle manière à obtenir une corrélation maximale entre l'éclairement semi-cylindrique modifié et la reconnaissance du visage. Ainsi, le concept de source lumineuse "effective" et de modelé d'objets et visages tri-dimensionnels a été discuté.

ÄNDERUNG DES KONZEPTS DER HALBZYLINDRISCHEN BELEUCHTUNGSSTÄRKE : WEITERE UNTERSUCHUNGEN ÜBER DIE GESICHTSERKENNUNG

ZUSAMMENFASSUNG

Das Konzept der halbzylindrischen Beleuchtungsstärke ändert sich durch Abkappen des vertikalen halben Zylindermantels. Das Abkappen wird so durchgeführt, daß die Korrelation zwischen der modifizierten halbzylindrischen Beleuchtungsstärke und der Gesichtserkennung maximal ist.
Zudem werden das Konzept der "effektiven" Leuchte und die raumliche Bewertung von Objekten und Gesichten erörtert.

KEYWORDS : Illuminance, visibility, urban lighting, street lighting, exterior lighting

1. INTRODUCTION

Recognition and identification of human faces and three-dimensional objects can be described by means of the semi-cylindrical illuminance. Under practical conditions this is expressed as a relation between the recognition distance and the value of semi-cylindrical illuminance at average face height.
The main design criterion for residential area lighting is therefore recovered as conditions on absolute minimum level and distribution of semi-cylindrical illuminance [1].

There is however need to refine and to ameliorate the way facial recognition is translated into quantifying, objective and measurable parameters.
In a first step, the theoretical concept of the semi-cylindrical illuminance itself will be modified by vertically truncating the receiving surface of the upright half cylinder.
T. Inoue *et al.* introduced the concept of modified semi-cylindrical illuminance in [2].

In residential area lighting as in other applications one of the major problems is to define the "effective" light source properly. Under effective light source one may understand that light or light source contributing actively to the seeing task. For instance, lighting from behind the object person can contribute to a certain extent to facial recognition.
In a second step, the maximum angle of incidence with backward lighting will be determined in function of the actual ability to recognise a face or an object, under the most unfavourable conditions (unidirectional light incidence).

A laboratory lighted scene was set up to examine these aspects with a considerable group of observers. Particular emphasis was put on the nature of the coherence between the amount of light in terms of (modified) semi-cylindrical illuminance and the spatial distribution in terms of three-dimensional modelling and restauration of objects. These laboratory experiments were then repeated and completed in a real outdoor environment.

2. ON MODELLING

The direction and the directional density of light incidence is strongly affecting recognition. Typical positions correspond to frontal, sideward and backward lighting which mostly has been considered as non-contributing to facial recognition.

2.1 Luminance Contrasts

In addition to the amount and the direction of incident light on a human face or a three-dimensional object, there is another aspect to look at.
In quantifying facial recognition we do not refer to luminances as it is extremely difficult and hardly unfeasible to express recognition in these terms. After all, neither averaging luminances over the face or object, nor considering the complete luminance distribution has a visual significance when it concerns recognition.

However, this does **not** imply recognition is considered in a non-luminous environment.
The lit environment is obviously presenting luminance contrasts between visually significant zones or patches.

In public lighting, both positive and negative contrasts eventually occur with frequent turnover from one type to another. Actually, strong negative contrasts of objects of interest with background can have pernicious consequences on visibility and recognition. As in counter beam tunnel lighting the object in question will be seen in silhouette, as a surface, darker than the surrounding. The surface of this three-dimensional object will appear flat and as a result modelling will be very poor. Therewith visual acuity will go down seriously.
In spite of the greater sensitivity of the visual system for negative contrasts on transitions between darker and brighter zones, this particular conditions will aggravate facial recognition.

Moreover, bright surroundings attract attention of the eye; they create a veil, a background haze which can effectively lead to disability glare. Such surroundings correspond to peripheral vision where the eye rod receptors are intervening, which are a lot more sensitive than the receptors in the central zone.

All this leads to discomfort, and what's more, to serious loss of three-dimensional restauration and spatial sensation.

2.2 Diffuse and direct light incidence

Apart from positive and negative luminance contrasts, there is the modelling power of diffuse versus direct lighting. It is the expression of the influence of the purely geometrical nature of light incidence on three-dimensional restauration (and colour appearance). Diffuse lighting (associated with positive or negative luminance contrasts) will **always** create poor modelling and colour distortion with all metallic and most non-metallic surfaces.

2.3 Modelling power

Although the semi-cylindrical illuminance, the parameter for recognition, is describing the spatial density of incident light and therewith expressing a certain balance between frontal, sideward and backward lighting, the dynamical aspect of lighting of three-dimensional structures is more comprehensive than can be expressed by this parameter.

In residential areas incidence often takes place mainly from one direction. At the same level of the three-dimensional illuminance, it has been found recognition is facilitated when light is incident from more than one direction from both sides of the object person. This effect is more pronounced with higher levels of semi-cylindrical illuminance.

Particularly when light is mainly incident from one direction, recognition will be described by a combined criterion of semi-cylindrical illuminance and an adequate modelling parameter.

To describe the modelling power of the residential area lighting installation, a parameter has been defined as the ratio of the vertical to the semi-cylindrical illuminance according to the normal of the half cylinder at face height. It is the ratio of two "vertical" components in view of relatively low installation heights.
There is further need to modify this parameter because of the fact that it is a ratio of integrated quantities, showing ambiguous results in some circumstances.

3. MODIFIED SEMI-CYLINDRICAL ILLUMINANCE

The relationship between the recognition distance d [m] and the semi-cylindrical illuminance E_{SC} [Lux] can be estimated well analytically.
This is done by means of an exponential expression (in case of a low degree of disability glare, T. I. ≤ 2) :

$$E_{SC} = 0{,}09 \;.\; 1{,}42^{d} \qquad (1)$$

In order to further improve the correlation between recognition (distance) and three-dimensional illuminance, we opted for touching up the theoretical concept itself of E_{SC}.
It is found that for a great number of residential areas the most unfavourable position for recognition is systematically differing (albeit not much) from the position of minimum E_{SC}. See also [2]. This small anomaly is due to the fact that sources from behind the object person are given too great weight.

The concept of E_{SC} is then modified by vertically truncating the receiving surface of the upright half cylinder. See Figure 1. Herein is L the light source; r and h the dimensions of the convex cylindrical surface; φ the azimuth plane angle between the plane of incidence and the plane of observation; φ_c the azimuth plane angle of truncating.

In function of φ_c, the corresponding projected areas can be calculated and consequently $E_{Mod\ SC}$ can be determined.
The methodology to determine the truncating is such to obtain maximum correlation between the "modified" semi-cylindrical illuminance and the distance of recognition.
The maximum correlation is corresponding with $\varphi_c \approx 15°$.
Yet, the correlation is depending on the direction of incident light i. e. the azimuthal position φ of the luminaire with respect to the viewing direction of the observer.
From there, the angle φ_c of truncating cannot be defined unambiguously.

Experiments show that recognition is not affected much when the viewing directions of the object person and the observer (the latter defining the normal to the three-dimensional receiving surface) are differing not more than 30° in azimuth. One can understand this, as the azimuthal position curve $(1 + \cos\varphi)$, defining E_{SC}, takes the value 2 at $\varphi = 0°$ and the value 1,87 at $\varphi = 30°$.

In the immediate surrounding of a luminaire the illuminance E_{CS} on spherical cap with horizontal normal is to be applied instead of E_{SC} or $E_{Mod\ SC}$. This zone corresponds to distances to the luminaire lower than approximately 0,58 (H - 1,5) with H being the luminaire height in m.

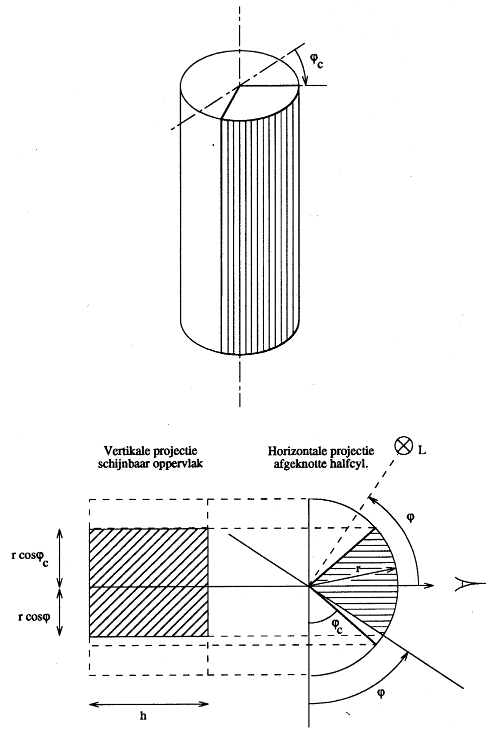

Figure 1 :
Modified semi-cylindrical illuminance $E_{Mod\ SC}$ (top), horizontal projection of truncated semi-cylinder (right) and vertical projection A_{Proj} {= $r.h(\cos\varphi + \cos\varphi_c)$ } of apparent surface (left) (Case where $\varphi_c < |\varphi| < \pi - \varphi_c$)

4. EFFECTIVE LIGHT SOURCE (WITH BACKWARD LIGHTING)

With plane vertical illuminance, the light sources contributing effectively to this parameter can be clearly determined.
With convex receiving surfaces, even small, as with E_{SC}, light sources from behind the object person do contribute, as they do to facial recognition. See Figure 2.

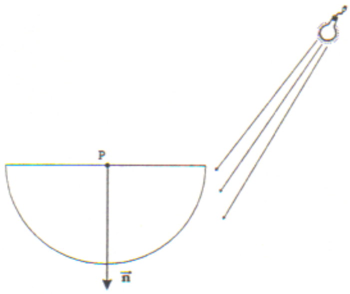

Figure 2 : Light sources from behind the object person do contribute to E_{SC} (top view)

The maximum angle of incidence with backward lighting has now to be determined in function of the actual ability to recognise the object person under the most unfavourable conditions (unidirectional light incidence). As a matter of course, the modified semi-cylindrical illuminance level on the object person's face was calculated.
The parameter $E_{Mod\ SC}$ was varying from 0,25 to 7 Lux. Observation took place at distances shorter than predicted by the expression (1).

In Figure 3, a top view of the experimental set-up is sketched. Object person and observer are indicated.

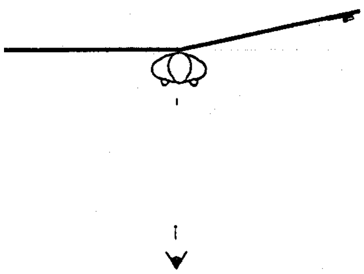

Figure 3 : Top view of experimental set-up to determine effect of backward lighting

A great number of persons participated in the tests. In function of $E_{Mod\ SC}$ on the object person's face, the limit azimuthal position φ of the light source with respect to the viewing direction was then determined.
When averaged, this relation can be written as :

$$E_{Mod\ SC} = 1{,}46\ e^{-41}\ .\ \varphi^{20{,}05} \qquad (2)$$

Herein is φ the azimuth angle in degrees between the plane of incidence and the plane of view.

What can we conclude from the tests and from that "effective light source curve" (2) ?

1) At currently occuring levels of $E_{Mod\ SC}$ between 0,5 and 5 Lux, the average limit angle φ for backward lighting can be set to 114°.
2) The absolute maximum angle for backward lighting, regardless of the level of $E_{Mod\ SC}$, is found to be 125°.
3) Recognition can take place for φ > 114° at higher levels of $E_{Mod\ SC}$. In these cases, modelling becomes very dramatic because of the strong asymmetrical light incidence.

5. CONCLUSION

We can state that we have achieved a better quantification of the seeing task "recognition and identification of persons and objects". We also developed a methodology to fulfil visibility criteria in residential area lighting, even with a (slightly) reduced amount of lumens installed.

6. ACKNOWLEDGEMENTS

Much is endebted to Pascal Blondeel who largely contributed to the project.

7. REFERENCES

[1] : ROMBAUTS P, VANDEWYNGAERDE H, MAGGETTO G, *Minimum semi-cylindrical illuminance and modelling in residential area lighting*, Lighting Res. & Technol. 21 (2), pp 49-55, 1989.

[2] : INOUE T, SAKAMOTO S, UNO C, OKAMURA T, *Applicability of semi-cylindrical illuminance in designing road lighting in residential areas*, Journal of Japanese Illumination Society, 1989.

Patrick ROMBAUTS, Vrije Universiteit Brussel, Electrotechnical Dept (ETEC), Pleinlaan 2,
B-1050 BRUSSELS, Belgium, EUROPE