VISIBILITY MEASUREMENTS WITH CCD IN ROAD LIGHTING

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Abstract

The paper describes the evaluation of visibility levels for road lighting in Tucumán, Argentina, by means of CCD image processing. The visibility is evaluated for flat standing targets of 20x20 cm with 10, 25, 35, 48 and 58% reflectance at different locations over the road.

The methodology employed, the equipment used, its calibration and the data collected for the evaluation of visibility are described. The results obtained are discussed and compared with conventional measurements and theoretical calculations.

1. Introduction

The evaluation of the visibility levels of targets over the roadway requires the measurement of target luminance, immediate surrounds luminance and background luminance. Collecting luminance data point by point from a complex image with a conventional equipment requires care and time what can be solve using a CCD camera with an image processor and a calculation software. Moreover some restrictions can appear when a luminance meter with a proper field measurement window to assure measurement over the target is not available. This was the case when the experience was build.

The target studied is a flat square object of 20 x 20 cm standing over the roadway and facing the driver's view. From the viewing position the target angular size is 7 to 11 minutes.

The CCD camera captures the scene and allows an image processing. The image is transformed in numerals, which can be correlated to photometric values. In this way a luminance map from the image can be built and luminance over the different components can be analysed to calculate visibility levels based on Adrian model [1].

The paper describes the methodology applied, the equipment used, the calibration and the data acquisition for visibility level evaluations. Theoretical calculations based on luminaire photometry and lighting installation geometry are compared with results from the image processing.

2. The measuring equipment

2.1 The CCD camera

A CCD (charge coupled devices) is a silicon wafer that when light photons impinge the sensitive area, accumulates charge carriers in designated discreet locations storage elements. After an integration time charge carriers are transferred under the silicon substratum toward the output records, giving rise to a new proportional charge accumulation to the incident radiation. Each storage element of the silicon is known with the name of pixel [2] [3]. For the development of a first prototype a camera, resolution 756 (H) x 581 (V) with sensitive area of 8.4 mm x 6.4mm was used [4] [5]. The pixel average angular size is 2.4 minutes.

2.2. The image acquisition board

The CCD analogical output signal needs a previous processing before being converted in an image to be viewed in the TV monitor. The image acquisition board card modifies the analogical camera signal, first by means of the of the gain G adjustment and the offset O, positioning the “zero” level of the signal in a determined value, corresponding to dark current. Then, the signal is digitalized in real time at the analogical-digital converter (A/D). This produces an integer value of 8 bits between 0 and 255. For the input signal from each pixel the system will assign a spatial co-ordinates and a value; this value is named grey level (Ng) and vary between 0 and 255.

In the following processes the signal, in the form of digital image, will be stored in an a RAM memory type; it could also be manipulated by means of filtered, logarithmic transformation, exponential, gaussian, histogram equalization, etc. Finally, at the output, the signal goes to a digital - analogical converter (D/A) in order to be observed at a TV monitor.

The image acquisition board [6] and the image processing software [7] were installed in a personal computer. The basic operation plan of the system is shown in the figure 1.

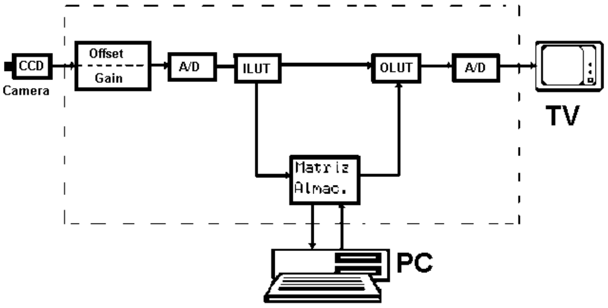


Fig. 1: Basic system outline

2.3. Adjustment of the system " zero level "

In the absence of light over the CCD detector, a signal is generated called "dark current" which has to be compensated to establish a zero reference value. This current will increase with the temperature increase of the silicon, and the visible effect of the dark current will be greater with larger exposition times.

The compensation procedure consists in acquiring one or more images with the camera lens cap on in order to avoid the luminous over the wafer of silicon. Next, an analysis of the images by means a histogram of grey level frequencies in the image area selected, obtaining the minimal, maximum and average Ng values and also their corresponding standard deviation [3]. For this experience we have measured $\mathbf{Ng_0}$ = 6. This is the minimal useful grey level.

2.4. Spectral Analysis

The CCD spectral sensibility to the luminous radiation, given by the manufacturer, is indicated in the figure 2 with the human visual system response for a standard observer established by the CIE. To match CCD response with the CIE curve in the 360-830 nm interval a filtering and / or attenuating is required. The above IR and under UV wavelengths radiation's should be cut off.

Former experiences showed that the system CCD – image acquisition board can have a good behaviour as a spatial resolution luminance meter [5] [8] [9], specifying a curve of $L = f(E_i, \tau, \alpha, f_n, T_c\,[^\circ K],..)$,with a previous spectral response correction for the CCD matching the human eye t response $V(\lambda)$ of the CIE.

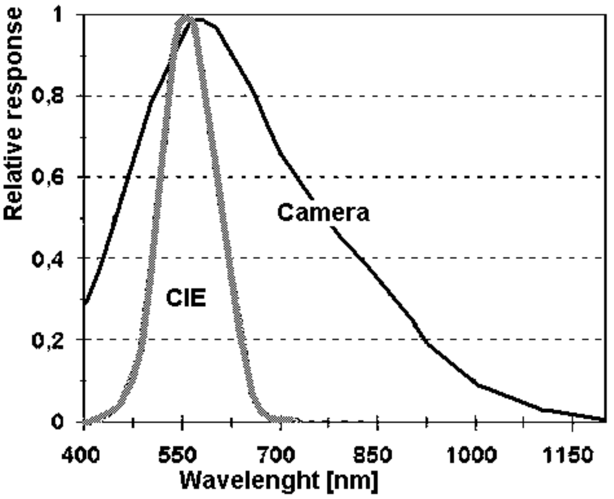


Fig. 2: Relative responses from CCD and from human eye according to CIE.

2.5 Photometric calibration for images acquisition

A $V(\lambda)$ filter [10] was incorporated to the camera, placed between the silicon wafer and the optical system in order to assure a proper response.

For the video output signal it is desirable a linear response from the photons impacts at each pixel, the function that relates the luminance L with each grey level Ng must be an expression of the form:

$$Ng = m\,L + Ngo$$

where m is the line slope and Ngo the grey level for "darkness" that is the video output signal without luminous input.

System calibration was done acquiring images with different luminance levels but from a uniform and constant field. For that propose a small integrating sphere with a constant, uniform and stable luminous opening was used. Different levels were possible with the aid of neutral filters. The absolute luminance value over the field was measured with a luminance meter.

For each image acquired a luminance L and a grey level Ng was associated for which a spot was generated. Repeating the process for different luminance levels linear regression L vs Ng was built.

The procedure was also repeated for each diaphragm apertures ***f***:

f	**Linear regression**	**Luminance interval cd/m²**	**error**
1.4	$L_{1.4}=(Ng–5.38)/12.97$	0.6<L<16	7%
2	$L_2 = (Ng – 5.63)/7.57$	1.0<L<32	5%
2.8	$L_{2.8}= (Ng – 5.67)/4.47$	1.0<L<50	3%

The conversion for the photometric analysis of any visual scene captured by the CCD camera is now possible.

3. Visibility level evaluation

Visual performance of road drivers during night relies on the amount of visual information obtained of the roadway and the surroundings. A criteria that describes an important aspect of the difficulty of the visual task is the visibility of a "critical detail" on the roadway this is usually consider to be a 20x20 cm target located at 86m in front the driver [11]. It is assume that most drivers can clear this target size; in case of bigger objects these will be more visible. The distance also assumes a safe stopping from a moderate speed and normal reaction time. Although this criterion doesn't represent all the complexity of the visual task, it is frequently used.

A target is visible when it stands out of the background, in other words when it displays a contrast that can be defined in terms of the luminance of the object. The target appears in positive contrast when it is brighter than the background or in negative contrast when it is darker than the background (figure 3). When the difference of luminance between target and background is the minimal in order to perceive the target thresholds conditions are faced. Luminance contrast is defined as:

$$C = \frac{L_T - L_B}{L_B}$$

where

L_T : target luminance and L_B : background luminance

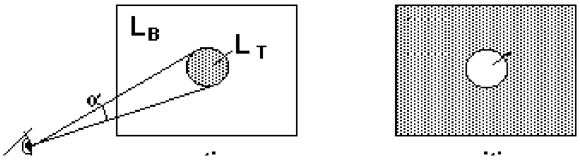


Fig. 3: Negative or positive contrast for a target with α angular size

The visibility level VL is the number of times in which the actual target is visible related to the threshold target visibility conditions. In terms of luminance VL is obtained by the ratio of the actual luminance difference between target and background to its threshold value.

$$VL = \frac{C_{actual}}{C_{threshold}} = \frac{actual}{threshold}$$

where:

C_{actual}: Actual target contrast = DL_{actual} / L_B

$C_{threshold}$:Threshold target contrast=$DL_{threshold}/L_B$

$DL_{actual} = L_T-L_B$

$DL_{threshold}$: Threshold luminance difference between target and background

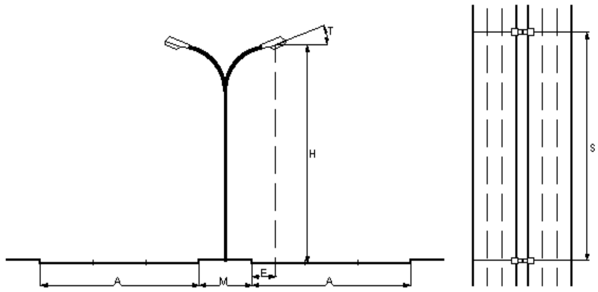
For safe and secure traffic conditions minimum maintained VL levels are recommended by CIE [12] according to the road type.

VL considers the influence of the size of the target, the contrast polarity (if it is positive or negative), the time of exposure, the age of the observers and glare. Adrian VL model [1] [13] is applied in order to calculate VL.

The equations used from the model are indicated in annex I. More details can be found in references [1], [11] and [13].

4. Methodology

A road lighting installation with one year running in the city of S.M. de Tucumán, Argentina was selected for the experience. The installation is described in figure 4.



Road arrangement::	Central
Central width (M):	8m
Road width (A) :	12m
Nº lanes:	3
Road surface:	CIE R3
Luminance coeff. Qo:	0.1
Height (H):	12m
Spacing (S):	36m
Overhang (E):	-0.5m
Tilt (T):	15º

Fig. 4: Experimental road lighting installation

Luminaries photometry and lamp flux measurements were done at the lighting laboratory Depto de Luminotecnia Luz y Visión. (figure 5).

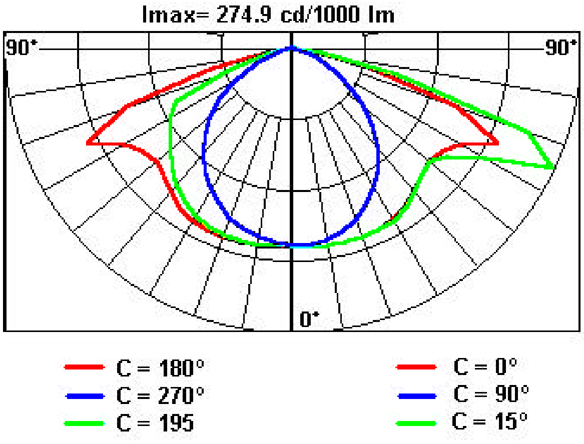


Fig. 5: Luminaire photometry from Strand MBA 70 CO, cut-off IP54. Lamp: Osram, high-pressure sodio tubular 400W.Lamp Flux: 44.861 lm.

The measurements carried out were a) horizontal illuminance Eh over a 5x10 grid, b) luminance at the same grid from 72m ahead and at 1/ 4 of the external border. Also images from the road alone and with the different targets arrays were obtained from which the grey levels were transformed to spatial luminance. During the measurements voltage installation was controlled. A summary of the measured parameters and the theoretical calculated values are indicated in table 1.

Table 1: Measurements and calculations of illuminance and luminance over a grid between two luminaries.

Source	Illuminance	Luminance
Pocket Lux meter	Eh_{ave} = 35 lux Eh_{min} = 12.9 lux Eh_{max} = 78.9 lux	
Luminance meter		L_{ave} = 3.4 cd/m² U_O = 0.51 U_L = 0.7
CCD as luminance meter		L_{ave} = 3.1 cd/m² U_O = 0.3 U_L = 0.56
Software output	Eh_{ave} = 33.3 lux Eh_{min} = 12.6 lux Eh_{max} = 78.9 lux	L_{ave}= 2.91 cd/m² U_O = 0.35 U_L = 0.72

5. Visibility levels calculated from CCD luminance measurements

The different alternatives of target positions and target surface reflectance produced 15 scenes the images of which were captured with the CCD camera. For each image grey levels were transformed in spatial luminance's by means of the previous calibration as descripted in 2.4.

Figure 6 shows an example of the experimental installation with targets aligned at x=1.2m from the central. From the image the target's luminance, the immediate surround luminance and the background luminance (road average luminance) were obtained in order to compute VL.

VL computed are indicated for internal line (x= 1.2m), central line (x= 6m) and external line (x= 10.8m) with the five possible target reflectance. The resulting curves are indicated in figures 7, 8 and 9.

Fig. 6: Road lighting installation array with target aligned at x=1.2m.

At the experimental road, $|VL| > 7$ in order to agree with recommended maintained value [12]. The VL calculated from CCD luminance measurements are shown at figure 7, 8 and 9.

At $x = 1.2$m $|VL| < 7$, for $35<\rho<48\%$ in the first half of the area between two poles and for $\rho>48\%$ in the second half. $|VL| > 7$ for targets with $\rho<35\%$ reflectance.

At $x = 6$m (central line) $|VL| < 7$, for $25<\rho<48\%$ and for $\rho>48\%$ at the last tree positions. $|VL| > 7$ for targets with $\rho<25\%$ reflectance.

At $x = 10.8$m $|VL| < 7$ for most cases except for $\rho>58\%$ at the central positions.

7. Discussion

Comparing measurements with calculations in table 4.1 it can be observed:

a) E_{ave}, calculated, considering the existent depreciation of 0.9 and over the same grid has a 5% difference from the measured value.

b) The L_{ave} obtained with CCD shows an acceptable difference within the 10% from calculated value. Similar results are found for U_O and U_L.

c) Target luminance's measured with CCD and calculated do not show a high correlation possibly differences in the geometry of the installation. This already well known fact is well described by Lewin [14]. Target luminance with 10% reflectance were very low to be measured with CCD therefore were not considered in the analysis.

d) Measurements of L_{med},, U_O and U_L with luminance meter are indicated not as reference values provided that they were done with a 6 minutes measuring window which, produces a long oval figure on the roadway instead of a point [5]. Nevertheless the difference with CCD measured values is less than 13%. With CCD camera de average pixel size is 2.4 minutes, which allows a more precise measurement from this point of view.

In consequence the luminance measurements with CCD would be reliable in order to calculate the levels of VL with an acceptable error.

Even if the installation fulfils the CIE recommendations for luminance levels recommendations [5], zones would exist where the visibility could be $|VL| < 7$ according to the target reflection considered.

8. Conclusions

The utilisation of CCD as a luminance meter in order to calculate VL has big advantages because it reduces the time required for the luminance distribution measurements and allows a more fine analysis from the image details. With conventional luminance meter some details could escape of the analysis or positional errors could appear. There are still limitations concerning with the reliably with low levels especially under 0.7 cd/m². This range has probably been reduced from the time the experience was done as CCD technology has improved.

9. Acknowledgements

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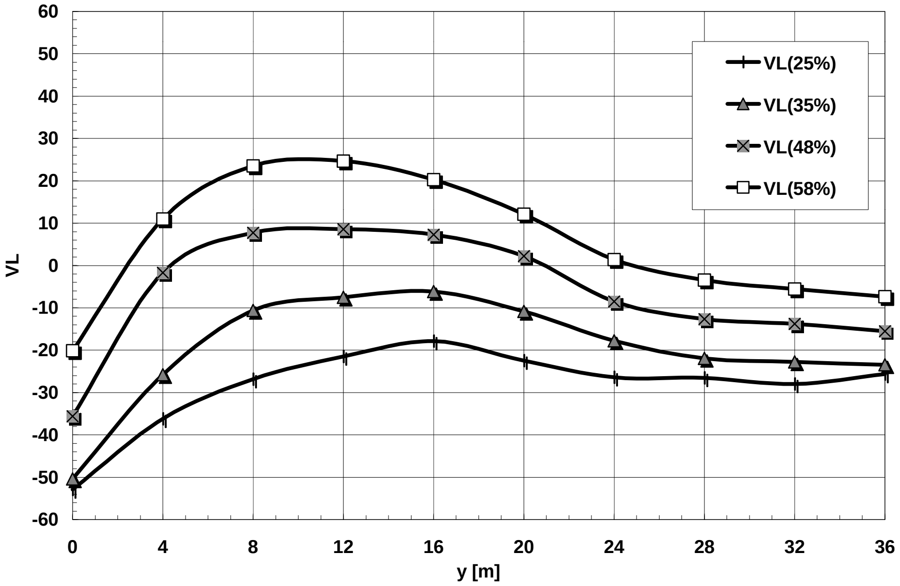


Figure 7: VL calculated from luminance measured with CCD at x = 1.2m with target surface reflection 25, 35, 48 and 58 %.

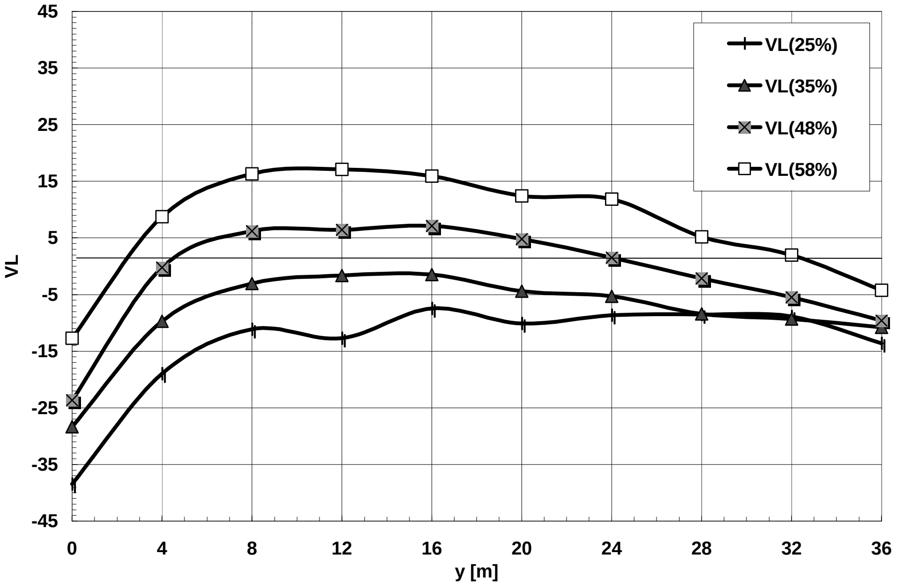


Figure 8: VL calculated from luminance measured with CCD at x = 6m with target surface reflection 25, 35, 48 and 58 %.

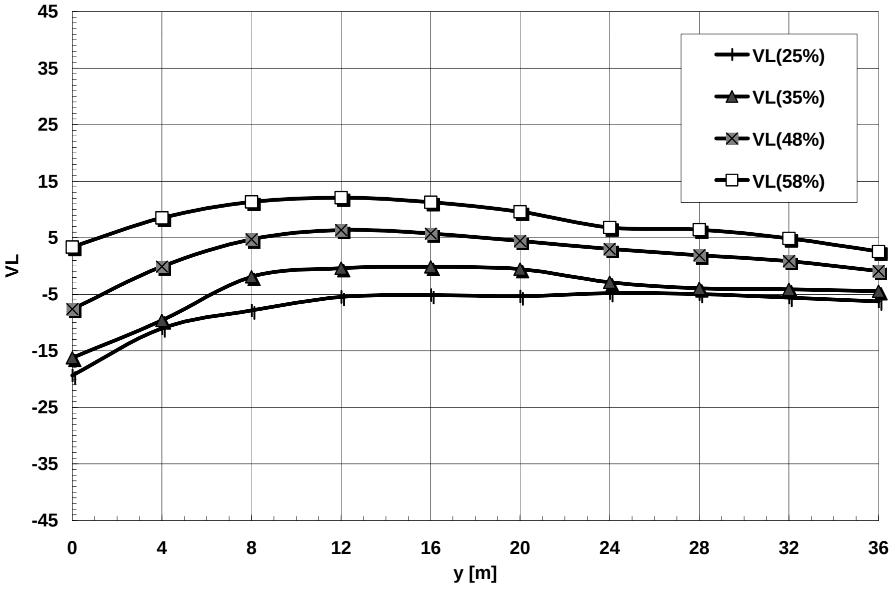


Figure 9: VL calculated from luminance measured with CCD at x = 10.8 m with target surface reflection 25, 35, 48 y 58 %.

10. Annex I

The threshold luminance difference ΔL$_{\text{theshold}}$ is calculated from:

$$\Delta L_{\text{threshold}} = 2.6\cdot\left(\frac{\Phi^{1/2}}{a}+L^{1/2}\right)^2\cdot F_{CP}(a, L_B)\cdot a.(a, L_B)\cdot AF$$

where:

$2.6\cdot\left(\frac{\Phi^{1/2}}{a}+L^{1/2}\right)^2$ is the threshold luminance difference for positive contrast, observer average age 23 years and a 2 sec or unlimited observation time. This is a function of size (Ricco and Weber) and background luminance.

For L$_B$ ≥ 0.6 cd/m²

$${}^{1/2} = \log(4.1925\cdot L_B{}^{0.1556})+0.1684L_B{}^{0.5867}$$

$$L^{1/2} = 0.05946\cdot L_B{}^{0.466}$$

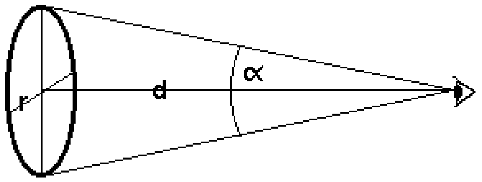
For 0.00418 cd/m² < L$_B$ < 0.6 cd/m²

$$\log \quad {}^{1/2} = 0.072+0.3372\cdot\log L_B + 0.0866(\log L_B)^2$$

$$\log L^{1/2} = -1.256+0.319\cdot\log L_B$$

α : Target angular size [minutes]. A circular target with radius *r* seen from distance *d* has an angular size:

$$a = 2\cdot tan^{-1}\left(r/d\right)\cdot 60$$



$F_{CP}(a, L_F) = 1-\frac{m\cdot a^{-b}}{2.4\cdot\Delta L_{POS}}$: contrast polarity factor. Is 1 for positive contrast and less than 1 for negative as targets are more visible. Where *m* comes from:

$$\log m = -10^{-\left(K\cdot(\log L_B+1)^2+0.0245\right)}$$

K=0.125 for L_B > 0.1 cd/m²

K=0.075 for L_B > 0.004 cd/m²

$b = 0.6\cdot L_B{}^{-0.1488}$ for any L_B

$a(a, L_F) = \frac{\left[a(a)^2 + a(L_F)^2\right]^{1/2}}{2.1}$: exposure time . influence

$$a(a) = 0.36-\left(\frac{0.0972\cdot A^2}{A^2-2.513\cdot A^2+2.7895}\right)$$

$$A = (\log a + 0.523)$$

$$a(L_F) = 0.355-\left(\frac{0.1217\cdot B^2}{B^2-10.4\cdot B+52.28}\right)$$

$$B = (\log L_F + 6)$$

AF : influence of age

23y < *age* < 64y

$$AF = \frac{(age-19)^2}{2160}+0.99$$

64y< *age* < 75y $\qquad AF = \frac{(age-56.6)^2}{116.3}+1.43$

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