White Paper

Automotive Biometric Automatic Luminance Control System

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Automotive Biometric Automatic Luminance Control System

Paul Weindorf, Paul Morris, Shadi Mere
Visteon Corporation, Michigan, USA

Abstract

The use of an eye gaze tracking camera is proposed to measure the driver's pupil size and provide forward field of view intensity. This biometric intensity may be utilized as part of an automatic luminance control system to properly control the display luminance for comfortable display visibility.

Author Keywords

display; HUD; automatic; luminance; light; sensor; logarithmic; eye; tracking; gaze; camera; biometric

1. Introduction

"As displays are utilized more often in automotive applications, the importance of being able to see the display presentation under various lighting conditions becomes important. As the automotive display luminance requirements are increasing beyond 1000 cd/m^2, the need to automatically adjust the display luminance to the value necessary for visibility is becoming important in order to minimize display temperatures. With the advent of automotive organic light emitting diode (OLED) displays, there is also a need to reduce the average luminance to minimize burned-in image artifacts" [1]. As discussed in reference [1], a forward looking light sensor is required to properly address the problem of light adaptation when the driver is looking out of the windshield at a bright scene and then looks at a center information display whose luminance is determined via ambient light sensor(s) that may be shadowed as depicted in Figure 1-1. Instead of using a forward looking sensor proposed in reference [1], this paper proposes using the driver's pupil size to more accurately determine the required display (including HUD, display mirror, etc) luminance.

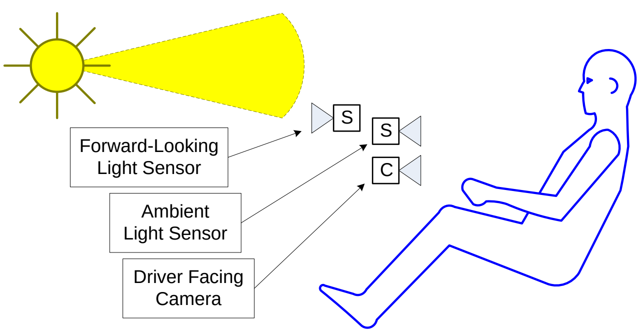

Figure 1-1. Forward Looking Light Sensor

Figure 1-2 shows a picture of an eye tracking camera image that may be used to determine the user's biometric pupil diameter. Measurement of pupil diameter ("pupillometry") can be done using a near-IR camera (typical minimum frame rate of 30 Hertz). If a corneal reflection method is used for gaze direction, then images may include a reference "glint" (highlight) from the illumination source. Pupil size is affected by external environment (ambient light, etc.) and other physiological factors (emotions, drug interaction, head injury, etc.). Measurement can be impacted by biometric factors (variation in age, eye color, etc.) and optical path (camera location, glasses, etc.). An example of dilated and constricted pupil, with corneal reflection "glint" is shown in Figure 1-3.

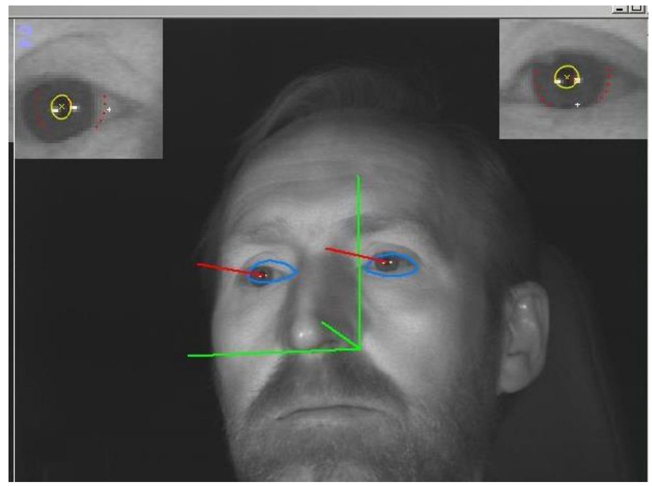

Figure 1-2. Eye Tracking Camera Images

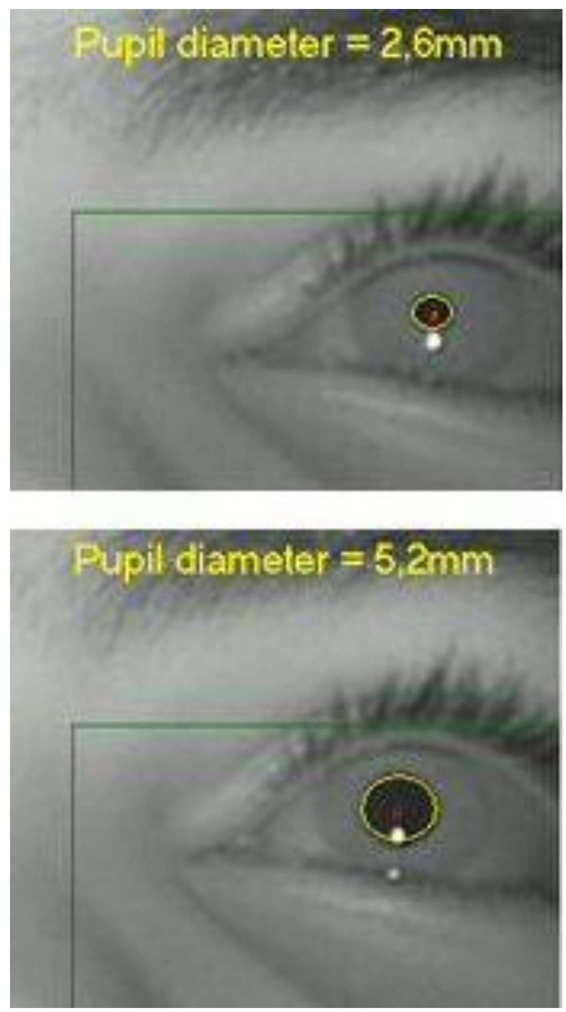

Figure 1-3. Pupil Diameter Pupillometry Showing "Glint" [2]

In addition to responding to light intensity, "the pupillary response is susceptible to illusions of lightness and brightness" [3] as shown in Figure 1-4.

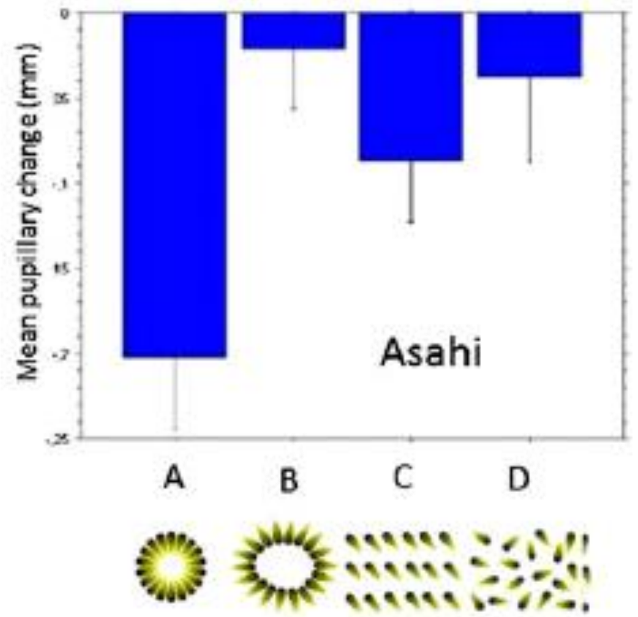

Figure 1-4. Pupil Response to Perceived Brightness [3]

By using the user's pupil size, automatic compensation occurs for field of view, perceived brightness, and other physiological considerations like the emotional state of the user which affects pupil size.

2. Background/Objective

The objective of this paper is to show how the driver's pupil diameter may be utilized as the forward looking light sensor for an automatic luminance control system. In order to use the biometric pupil diameter data from an eye gaze camera, a relationship between the pupil diameter and the forward field of view intensity is required. According to "A unified formula for light-adapted pupil size" reference [4, Equation 21], a formula is proposed as shown by the dashed black line labeled "Unified" in Figure 2-1. In general from Figure 2-1, the log of user observed luminance L is a function of the user's pupil diameter D as represented by Equation 2-1.

$$\log(L) = f(D) \qquad (2\text{-}1)$$

The unified formula is adapted from the Stanley Davies (1995) formula [4, Equation 10] per Equation 2-2 which uses the concept of corneal flux density. Note that field of view area "a" in Equation 2-2 is in deg^2. Therefore the pupil diameter is not only a function of the luminance that the eye sees, but also responds to the viewing area "a" of luminance.

$$D_{SD}((L,a) = 7.75 - 5.75\left[\frac{(La/846)^{0.41}}{(La/846)^{0.41} + 2}\right] \qquad (2\text{-}2)$$

Inherent in the Silverstein "Forward Field of View Intensity" [5] is that it refers to corneal flux density. Therefore the correct function to utilize is per Equation 2-3 derived from Equation 2-2.

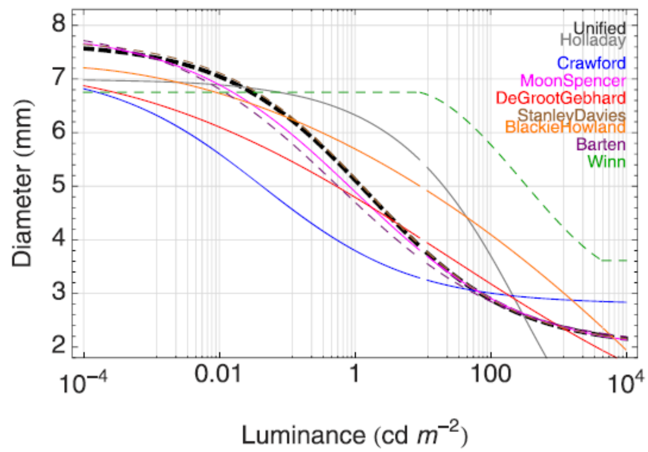

Figure 2-1. Pupil Diameter Functions [4, Figure 16], Unified parameters are: Age=30 years, Binocular Vision, 60° Field Diameter

$$\log(La) = \left(\frac{1}{0.41}\right)\log\left[\left(\frac{7.75 - D}{D - 2}\right)2(846)^{0.41}\right] \qquad (2\text{-}3)$$

Note that the age component may be calculated and used if the driver's age is known or the user may set a preference offset.

To explore the effects of age, the unified formula [4, Equation 21] may be written as Equation 2-4 assuming binocular vision.

$$D_U = D_{SD} + (y - y_0)[0.02132 - 0.009562 D_{SD}]$$

y_0 =28.58 years (2-4)

y = age in years

D_{SD} = Stanley Davies function per Equation 2-2

Manipulation of Equation 2-4 yields Equation 2-5.

$$\log(La) = \left(\frac{1}{0.41}\right)\log\left[\frac{\left[\begin{matrix}7.75 - D \\ -0.05279(y - y_0)\end{matrix}\right]2(846)^{0.41}}{D - 2 - 0.0022(y - y_0)}\right] \qquad (2\text{-}5)$$

Similarities between Equation 2-5 which includes the age factor and Equation 2-3 which does not include the age factor may be observed. Figure 2-2 shows an example of using Equation 2-5 for two different ages. Note that the age of 28.58 years simplifies Equation 2-5 to become Equation 2-3. Figure 2-2 shows that increased age minimally affects the pupil contraction for high luminance levels, but in a dark environment the aged eye does not dilate as much as a younger eye which may partially explain why older eyes have more difficulty in seeing at night. The working range for the auto luminance control will be approximately in the 4 mm to 2 mm pupil diameter range corresponding from 10 cd/m^2 to greater than 10,000 cd/m^2. If for example the age of the user is not known, the algorithm would resort to the worst case 60 year old eye. Different means could be employed to determine the log(La) as a function of the measured camera diameter according to Equation 2-5 such as direct calculation, lookup tables or other approximations such as a linear equation approximation or other equation approximations such as Taylor series. In the event that the pupil diameter cannot be measured due to squinting (reduced eyelid opening), eye tracker data which provides a percentage of eye closure relative to a nominal level may be used to predict a high luminance condition.

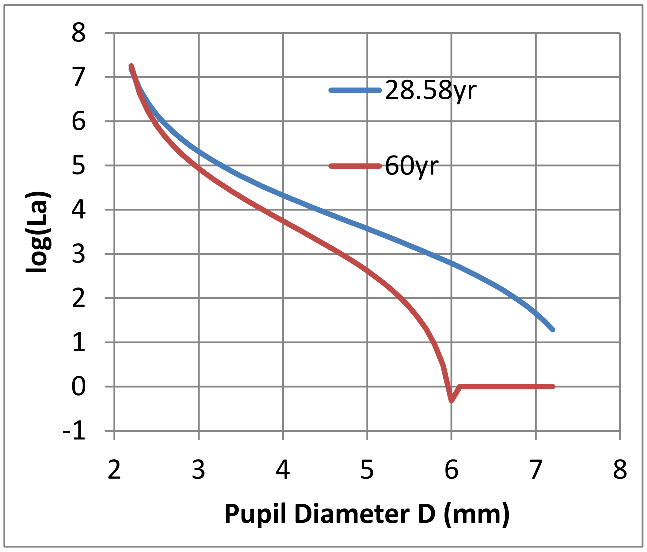

Figure 2-2. Ages Factor Example for Pupil Dilation

3. Implementation

A review of the concepts as described in references [1] and [6] form the basis for the automatic luminance control system. Based on human factor studies, Dr. Silverstein published his work which outlines an automatic luminance control system per Figure 3-1.

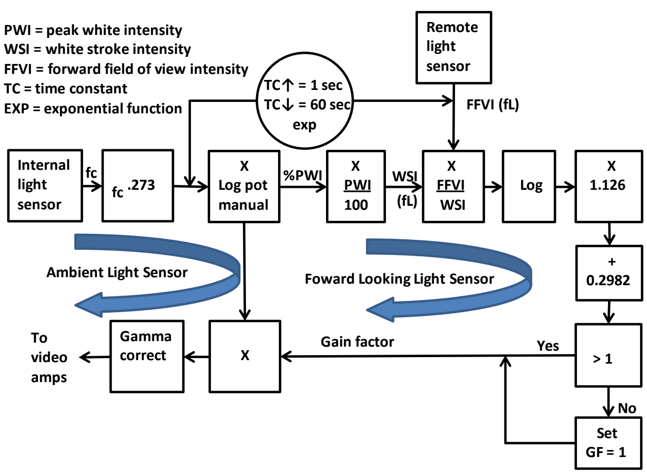

Figure 3-1. Silverstein Automatic Display Luminance System [5, pg. 304 redrawn for clarity and adapted with loop arrows]

In addition to increasing the display luminance as a function of the reflected display background luminance measured by the "Internal light sensor" (ambient light sensor) as shown in Figure 3-1, display visibility performance may be improved by the utilization of a forward looking "Remote light sensor" as shown in Figure 3-1 to compensate "for conditions of transient adaptation or eye adaptation mismatch" [5].

The ambient light sensor control loop of Figure 3-1 is based on the relationship of the required display luminance as a function of the display reflected background luminance as shown in Figure 3-2 and as described by Equation 3-1.

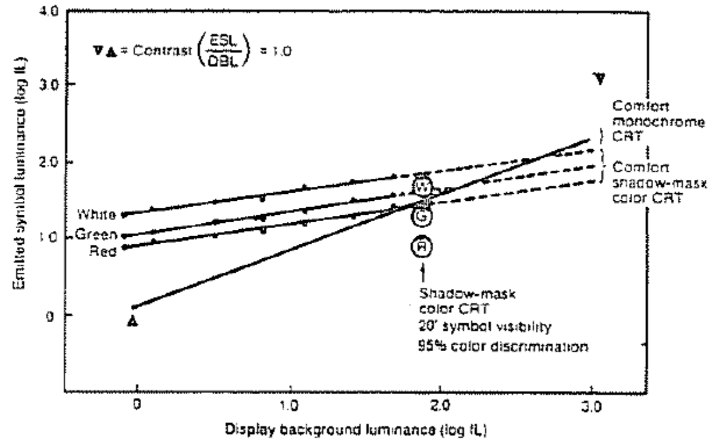

Figure 3-2. Display Emitted Symbol Luminance as a function of Display Background Luminance [5, pg. 274]

$$ESL = B_O (DBL)^C \tag{3-1}$$

- ESL = Emitted Symbol Luminance in cd/m^2
- B_O = Luminance Offset Constant
- DBL = Display Background Luminance in cd/m^2 proportional to the display ambient light sensor value
- c = Power Constant (This is the slope of the power function in logarithmic coordinates)

The forward looking light sensor loop as shown in Figure 3-1 results in the determination of a gain factor which is multiplied with the ambient light sensor determined display luminance to obtain the final display luminance. The gain factor (GF) required for this forward looking eye adaptation mismatch compensation as described further by Dr. Silverstein may be formulated by Equation 3-2.

$$GF = 1.125 \log\left(\frac{FFVI}{WSI}\right) + 0.2982 \tag{3-2}$$

- GF = Gain Factor
- FFVI = Forward Field of View Intensity
- WSI = Display White Stroke Intensity

Figure 3-3 shows the biometric implementation as modified from reference [1] where the forward looking light sensor is replaced by the eye gaze camera pupil diameter data.

Notice that the table in block 12 of Figure 3-3 is configured so that log(La) increases by equal increments.

It can be shown that for a table constructed with luminance ratio steps (block 4), the difference of the logarithms of FFVI (Δlog(FFVI)) between successive steps (block 12) is a constant according to Equation 3-3.

$$\Delta \log(FFVI) = \frac{1}{c(T-1)} \log\left[\frac{L_{Max}}{L_{Min}}\right] \tag{3-3}$$

c = Silverstein power constant

T = Total number of luminance steps

L_{Max} = Maximum luminance level

L_{Min} = Minimum luminance level

For block 13, the relationship between the luminance ratio step number N_H and the forward field of view (FFVI) may be developed according to Equation 3-4 where $FFVI_0$ corresponds to Step 0 of the luminance ratio table.

$$1.125\log_{10}(FFVI) = 1.125\Delta\log(FFVI) \times N_H + 1.125\log(FFVI_0) \quad (3\text{-}4)$$

Note that Equation 3-4 shows that a linear table may be constructed which related HUD step number N_H to the $1.125\log_{10}$(FFVI) since all the other terms are constants.

Although the operation of the rest of the elements in Figure 3-3 is described further in reference [1], it is helpful to provide a simple example to show how the system would operate. If the logarithmic ambient light sensors (blocks 1 and 2) have an A/D value of 423, then the display luminance would be determined to be 107.72 cd/m^2 per N_D step 4 from the luminance ratio table in block 4. However if the eye gaze system has determined a driver's eye pupil diameter of 2.9 mm associated with a log(La) of 5.393 per Table in block 12, let's assume that a GF gain factor of 3.11 is determined from block 7 based on the constant factors in blocks 6 and 13. The GF look up table (block 8) is then utilized to determine a ΔN value of 4 which is basically a multiplier function since the display luminance values (L_{SEL}) in block 4 are arranged as constant luminance ratios. Since the original ambient light sensor N_D step of 4 was determined from the ambient light sensor, the ΔN value of 4 is added resulting in a new N_D step of 8. Therefore the forward looking pupil diameter changes the display output luminance from 107.72 cd/m^2 to 299.74 cd/m^2 per step 8 in block 4.

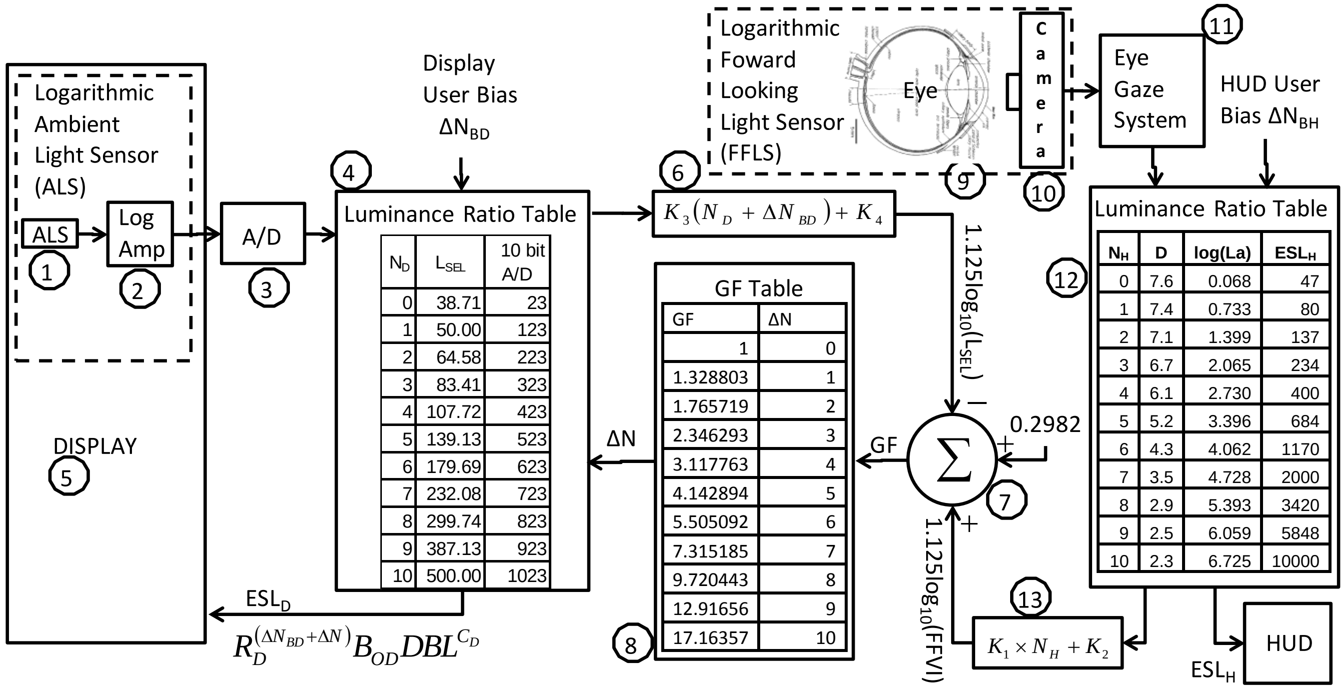

Figure 3-3. Automotive Biometric Automatic Luminance Control System

4. Conclusion

An automatic display luminance control system has been proposed that utilizes driver's biometric pupil diameter to determine the forward field of view intensity. Such a system is expected to perform better than a system utilizing a forward looking light sensor since actual driver forward field of view intensity data is being utilized. In addition, age compensation is possible. Finally the biometric forward looking sensor may be utilized by the HUD system to adjust the luminance of the projected image.

5. References

[1] Weindorf, P., Forward Looking Light Sensor Utilization for Automatic Luminance Control, Society for Information Display 2015 Symposium Digest of Technical Papers

[2] Image from http://www.metrovision.fr/mv-pu-notice-us.html

[3] Laeng, B., Endestad, T., Bright illusions reduce the eye's pupil, PNAS Direct Submission vol. 109 no. 6, 2162-2167, DOI 10.1073/pnas.1118298109, PubMed ID 22308422, 2012

[4] Watson, Andrew B., Yellott, John I., "A unified formula for light-adapted pupil size", Journal of Vission (2012) 12(10):12, 1-16. ISSN 1534-7362 © 2012 ARVO.

[5] Silverstein, Louis D., Merrifield, Robin M., Hoerner, F. C., The Development and Evaluation of Color Systems for Airborne Applications – Fundamental Visual, Perceptual, and Display Systems Considerations, Reference No. 851774, SAE, 1985

[6] Weindorf, P., Automotive Automatic Luminance Control, Society for Information Display 2014 Vehicle Displays and Interfaces Symposium Digest of Technical Papers.

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