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To cite this article: Ning Yang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **585** 012102

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Display Luminance Management Algorithm in Aviation Cockpit

Ning Yang, Chunling Zhao, Kezhi Zhang, Xinbin Yao

Shanghai Aircraft Design & Research Institute, COMAC, Shanghai, 201210, P. R. China

Email: yangning0528@163.com

Abstract. An effective and reasonable luminance control algorithm, with ambient and forward field of view illumination compensation, has been proposed. This paper analyses the airworthiness requirement and human eye characteristics in terms of visual sensitive and as the basis of luminance control research. This algorithm introduces the display luminance comparison method to maintain the luminance consistency among all the head-down displays. The relationship between display luminance and ambient light is realized by power function to approximate the eye logarithmic response. Based on Webber-Fechner law, the adaptive mismatch compensation is utilized for the eye adaptation for transitions from forward field of view luminance levels. Considering the compensation for the display aging and the individual preference, the log-linear manual adjustment could help the crew to achieve the comfortable visual effect.

1. Introduction

With the development of man-machine efficiency technology, civil aircraft is put forward higher requirements on the adaptive adjustment ability in the flight deck. The reasonable luminance adjustment methods ensure the crew to obtain the key flight information clearly and comfortably as the cockpit light levels change rapidly.

According to AC25-11A 16.a (3), the aircraft display system shall have the automatic luminance adjustment function to reduce the pilot workload and raise the display lifetime. Meanwhile, manual luminance control should be retained to provide for normal and non-normal operating differences so that the luminance variation is not distracting and does not interfere with the flightcrew's ability to perform their tasks [1]. TSO-C113/SAE AS8034B, 4.3.2.2 requires that if the display system has automatic adjustment function, the operation of this adjustment shall function under changing flight deck ambient light levels. Also, manual luminance control shall not be adversely affected by failure of the automatic luminance control [2, 3]. In recent years, most luminance adjustment algorithms for aviation display are optimized on the basis of Webber-Fechner law. Lv presented a stepped brightness adjustment algorithms [4]. Zeng gave an adaptive brightness adjustment system to reduce the effect of dynamic light environment [5]. The above algorithm does not consider the effect of external light on the intensity perception of the flightcrew.

In order to better research the effect of light on the intensity perception of the flightcrew, the visual characteristics of the human eye are analysed. On the consideration of the visual impact from internal and external ambient light in the cockpit, this paper proposes a luminance coordination algorithm applicable to various adjustment modes for aviation display.



2. Human Visual Characteristics

The human visual system has characteristics such as color perception, spectral sensitivity and visual masking effect. The retina contains a variety of linear bandpass filters with incremented frequency bandwidth. The retina divides the image into multiple frequency bands which are equally wide on the logarithmic coordinates. Therefore, the human eye's perception of the image (i.e. chroma, brightness) is non-uniform and non-linear.

2.1. Light Spectral Sensitivity

The human eye has different light sensitivity with different wavelengths from 380 to 780 nm. Under the condition of bright environment (5 nit), the human eye is most sensitive to 555 nm yellow-green light. In a dark environment (0.001 nit), the peak shifts to 510 nm green light. This visual sensitivity characteristic of eye is expressed by

$$\begin{cases} V(\lambda) = e^{-285.4(\lambda-0.559)^2} \\ V(\lambda) = e^{-321.9(\lambda-0.503)^2} \end{cases} \quad (1)$$

The curve of above function can be described in Figure 1.

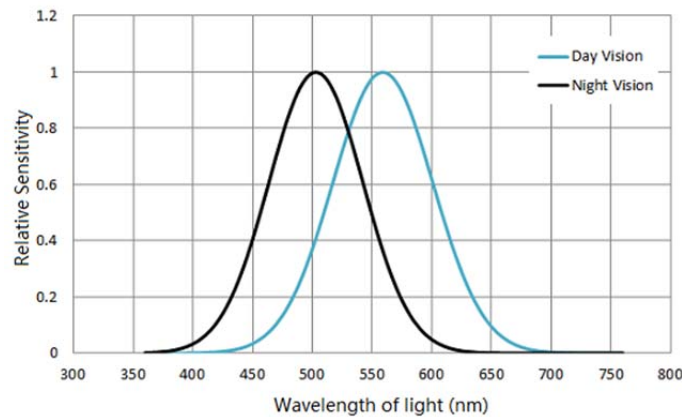


Figure 1. Human eye spectral sensitivity function

2.2. Luminance Sensitivity

As the ambient light changes, the human eye experiences scotopic vision, mesopic vision and photopic vision. As shown in Figure 2, each visual phase directly affects the human eye brightness perception on the observed object.

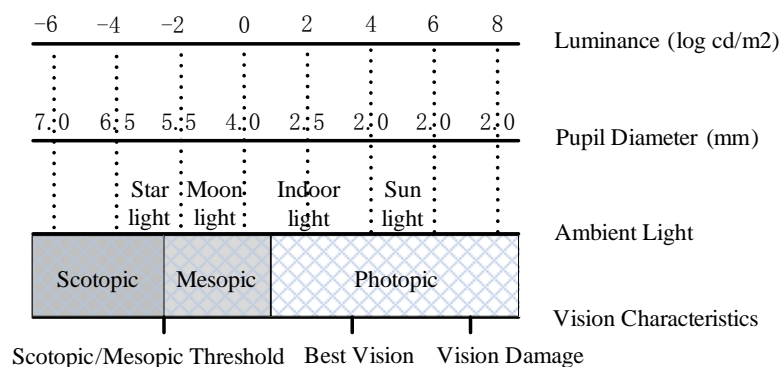


Figure 2. Human eye dark and light adaptation

2.3. Perceived Brightness Law

Human vision and brightness change of the observed object is in accordance with Webber-Fechner law, as shown in Figure 3. Below 0.01 nit brightness, human eye appears the weak vision. In the range

of 0.1 to 300 nit, the eye vision is proportional to the logarithm of the brightness. When the brightness exceeds 3000 nit, the human eye is at risk of damage.

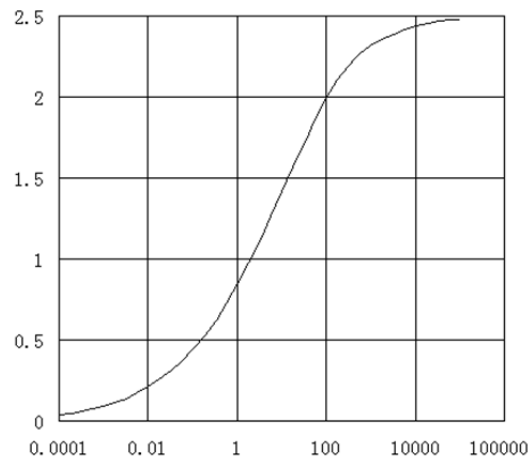


Figure 3. Human eye spectral sensitivity function

3. Aviation Display Luminance Control Algorithm

LCD display with LED backlight is common adopted in the civil aircraft cockpit. Compared to other backlights such as CRT, LCD display has wider luminance range and performs a better image performance under the intense light environment. When the flightcrew observes the flight information on the display, the human eye perceived brightness is not only related to the display hardware characteristics, but also determined by other factors such as the light outside the cabin and the ambient light in the cockpit.

Unlike the luminance control system of the mobile device, the aviation display requires a wide range adjustment method with the variety coordination luminance management ways. Based on ARP4032A section 6, the luminance management method should include the manual and automatic control, which means three luminance control algorithms are involved, namely manual luminance control, ambient illumination compensation and adaptive mismatch compensation. Figure 4 shows the luminance coordination algorithm structure for aviation display.

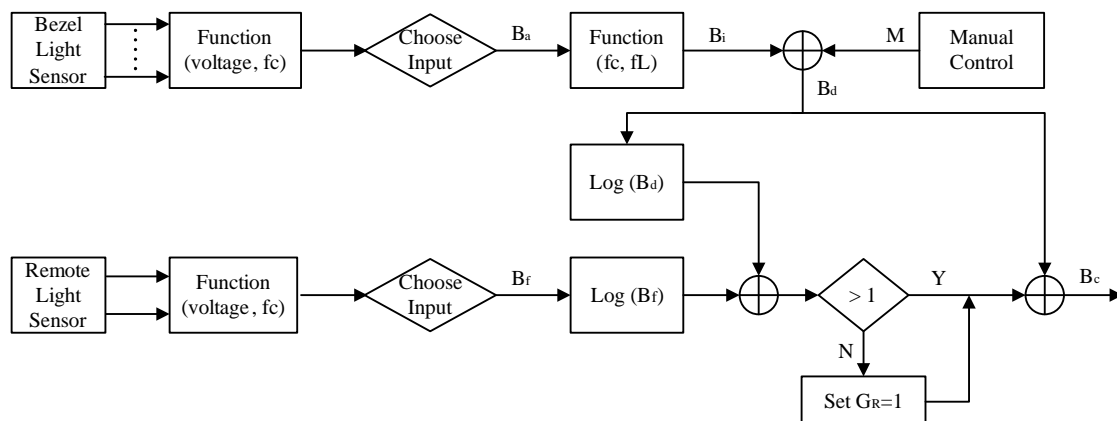


Figure 4. Display luminance control algorithm structure

3.1. Manual Luminance Control

The manual luminance control is applied to accommodate individual differences in the visual sensitivity of pilots and act as a spare control in case automatic function failure. In accordance with civil cockpit design philosophy, the manual control has a higher priority than automatic control for airborne system. Note that manual luminance control shall not be adversely affected by failure of the automatic luminance control.

The human eye response is approximately logarithmic, as described in Figure 3, requiring perceived brightness to change more at high luminance levels so as to achieve the same perceived change that it does at low luminance levels. Therefore, the rate of luminance change is greater near the top end of the control rotation than it is near the bottom. The manual luminance control is defined as a log-linear function, which is expressed as

$$G_M = 10^{K_1 M} \quad (2)$$

where G_M is manual control gain with a lower limit of 1; K_1 is a scaling constant and calculating value is 0.1; M is the manual luminance control ratio in the range from 0 to 1.

Manual luminance control is not act as the main control due to the displays are already being adjusted the automatic control as ambient light changes. The display aging compensation and pilots personal preference for luminance are realized by manual control.

3.2. Ambient Illumination Compensation

Each display in the cockpit should be equipped with an ambient light sensor (BLS) in response to ambient light changes. The cockpit includes some displays which receives BLS value from an adjacent on-side display. The final display BLS value is determined by the comparison between two adjacent on-side display BLS data. The display ambient light value comparison algorithm is shown in Figure 5 (five displays for example).

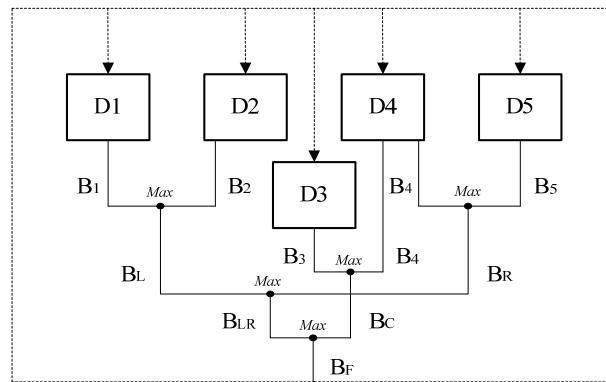


Figure 5. Aviation display BLS comparison algorithm

The above algorithm can ensure the adjacent on-side displays to maintain the same relative luminance when a single BLS failure or BLS data sudden changes caused by objects.

The LED device as LCD backlight is a linear device, that is, the relationship between luminance and current is a linear function. In order to make the LCD display effect conforming to human eye characteristics and preventing the display brightness level loss. It is customary to apply a non-linear transformation method to process grey scale data. In general, the power function is used to approximate the logarithmic function. The ambient illumination compensation algorithm, described as below, is proposed to reflect the relationship between the display luminance (B_d) and the cockpit ambient light (B_a).

$$B_d = K_2 B_a^{K_3} \quad (3)$$

where B_d is display luminance with unit fL and its luminance range is determined by display hardware characteristics. B_a is BLS value with unit fc and its range is from 0.3 fc to 8000 fc . K_1 and K_2 are scaling constants and K_2 is less than 1.0. Practical implementation result in a value of K_2 is 0.61 and K_3 is 0.1.

3.3. Adaptive Mismatch Compensation

Remote light sensor (RLS), typically placed on the flight deck glare-shield, is used to sense the forward field ambient light seen by the pilot looking out the windshield. Adaptive mismatch compensation is used to reflect the relationship between the brightness of the light in front of the

cockpit and the brightness of the display. The RLS value applicable to the control algorithm is the larger of two RLS data. The theoretical model of adaptive mismatch compensation is Weber-Fechner's law. According to Dr. Silverstein's derivation of the RLS gain expression [6], it can be expressed as

$$G_R = K_4 + K_5 \log \frac{B_f}{B_d} \quad (4)$$

where G_R is RLS gain. When RLS gain value is less than 1.0 the gain term is set to 1.0, so the RLS gain function never attenuates display luminance. B_f is RLS value with unit fc; K_4 and K_5 are constant value. Experimentation has calculated that an RLS gain function with $K_4=0.298$ and $K_5=1.125$ produces a luminance response that is preferred by flightcrew.

Combine the above three control algorithm, the final display luminance can be determined by the following equation

$$B_C = G_M G_R B_D \quad (5)$$

3.4. Filtering Control

Figure 2 demonstrates the characteristics of the human eye's bright and dark adaptation. Practically, the light adaptation is 1 min and the dark adaptation is around 30 min. The typical scene is the aircraft flying into and out of the cloud. When aircraft is flying out of a cloud into intense ambient light, the display must increase its luminance quickly to insure readability. When flying out of cloud into dark ambient light, the display must respond slowly to make eyes have adequate time to adapt.

It is necessary to add filtering function into the BLS and RLS compensation algorithm so as to conform to human eye response. An exponential filter adopts a time constant of 1 second or less for increasing light and 60 ± 5 seconds for decreasing light. This filter would not affect the display luminance response as the pilot manual adjustment or display reconfiguration.

4. Summary

In this paper, a luminance coordination algorithm for aviation display has been presented. The characteristics of human visual system are analysed as the basis of the following algorithm. Manual luminance control is used to accommodate individual preference and compensate the display aging. The automatic luminance control consisting of ambient illumination and adaptive mismatch compensation is introduced. The relationship between display luminance and ambient light is realized by power function to approximate human eye logarithmic characteristic. The BLS comparison algorithm is also proposed to maintain the same relative luminance for the adjacent on-side displays. Meanwhile, the Weber-Fechner's law-based RLS gain expression is given to compensate the forward field light sensed by the pilots. In order to ensure the eye bright and dark adaptation, an exponential filter with a time constant of 1s and 60s is employed for increasing and decreasing light, respectively.

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