The Glare Evaluation Method Using Digital Camera for Civil Airplane Flight Deck

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Abstract. Glare is a key factor influencing the visual performance in light conditions of civil airplane flight deck, but it is difficult to directly evaluate the complex glare sources in flight deck, such as non-uniform glare, irregular shape glare and indirect glare using current glare equations. In this paper, a method based on digital camera was proposed to evaluate glare is proposed to evaluate the glare from flight deck. Digital camera's imaging luminance measurement is based on High Dynamic Range (HDR) image processing. The computational procedures to calculate source luminance, background luminance, position index and solid angle of source, to detect the glare sources were developed in Matlab. And then, the desired glare index can be computed. Finally, Daylight Glare Probability (DGP) equation was utilized as an example to evaluate the glare for flight deck in daytime. The results indicate that the proposed method can compute glare index automatically and quickly.

Keywords: glare evaluation, digital camera, flight deck, fish-eye lens, glare index.

1 Introduction

Van Nakagawara[1,2] investigates the relationship between visual impairment from natural sunlight and aviation accidents. The glare was found to be a contributing factor. On the other hand, visual comfort has been a factor what need be taken into account in the flight deck designing. So, Glare is a strong factor to influence human-computer interaction of visual information in light conditions of the flight deck, and it is important to evaluate glare in flight deck. The glare sources of flight deck are very complex, including non-uniform glare sources, irregular shape glare sources and indirect glare sources, etc. And, as it is very difficult to compute luminance of reflective glare sources, these indices cannot evaluate indirect glare, such as reflective glare sources.

In our research work, we can use the glare evaluation method of flight deck based on digital camera to evaluate the glare of flight deck. The process of evaluation is shown in Fig.1.

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According to the different visual influence, glare can be generally divided into two types, discomfort glare and disability glare. In general illumination engineering, relative to the disability, the discomfort is more universal phenomenon. The method to control the discomfort glare can solve the disability glare problem. So, the glare we discussed is the discomfort glare in this paper. Several discomfort glare indices have been developed to assess glare from artificial light sources. These include: British Glare Index (BGI)[3,4], CIE Glare Index (CGI)[5], and Unified Glare Rating (UGR)[6]. And, there are several glare indices developed to evaluate the glare caused by daylight. These include: Daylight Glare Index (DGI)[7], New Daylight Glare Index (DGI_N)[8], and Daylight Glare Probability (DGP)[9]. In general, all these equations draw upon the four physical parameters, the luminance of the glare sources, the background luminance, the position index, and the solid angle. Especially, the vertical eye illuminance is also considered as a primary factor influencing glare index in the DGP[3].

In this paper, and DGP proposed by Wienold is utilized as an example to evaluate the glare for daylight in glare quantifiable evaluation of flight deck.

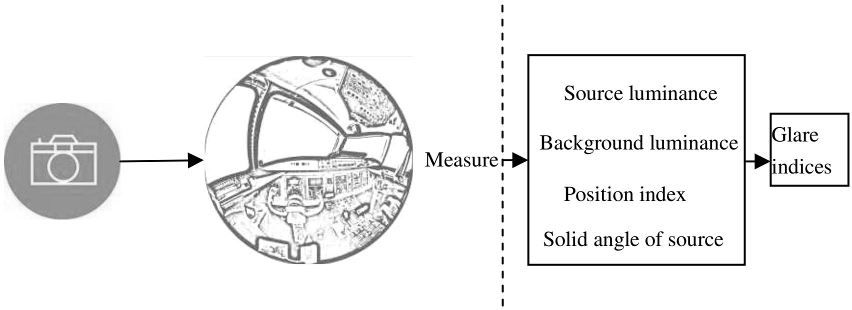

Fig. 1. The process of glare evaluation for flight deck

2 Equipment and Method

2.1 Method

Firstly, after analyzed the luminance of fields in scenes using a luminance meter at the time images are captured by digital camera whose lens is circular fish-eye lens, an empiric formula is developed describing the relationship between the luminance and the color record in the image. And then, the digital camera can measure the luminance of flight deck in 180° visual field. Secondly, glare sources are detected using computational procedures. The last stage computes source luminance, background luminance and position index and solid angle of source, and computes whatever glare index is desired.

Digital Camera's imaging luminance measurement is based on High Dynamic Range (HDR) image processing. Inanici[9] and Tse-ming CHUNG[10] have validated confidence in applying HDR photography as a luminance data acquisition system. The time scale exposure series of Low Dynamic Range (LDR) images to compose a high dynamic range image are used in the method. Then the tristimulus value is calculated from the RGB output by using the color space transformation. Finally the estimated value of luminance is computed by using the calibration coefficient obtained through physical luminance measurement from luminance meter.

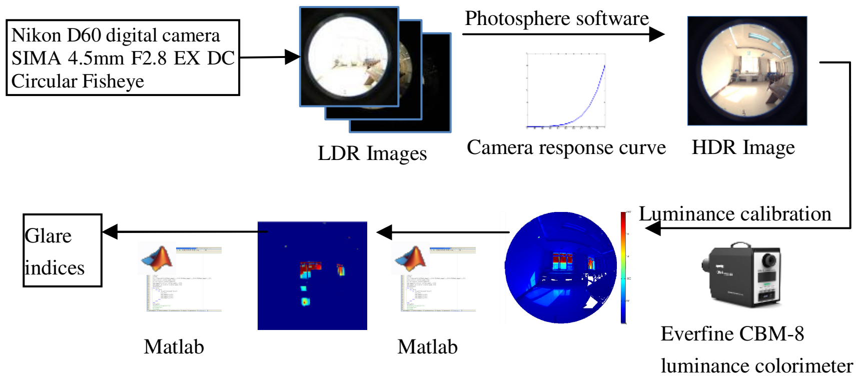

Fig. 2. The evaluation method based on digital camera

2.2 Equipments

The multiple exposure photographs were taken with a Nikon D60 digital camera mounted on a tripod and fitted with a fisheye lens (SIMA 4.5mm F2.8 EX DC Circular Fisheye). The fisheye lens has a focal length of 4.5 mm (equivalent focal distance 4.5×1.5mm) and an angle of view of 180°. Because of advantage to calculate solid angle easily, the fisheye lens we choose used equisolid projection mode. The projection mode of fish-eye lens is shown in Fig.3.

Reference physical measurements were taken with a calibrated luminance meter EVERFINE CBM-8 luminance colorimeter with 2°, 1°, 0.2°, and 0.1° field of view. The luminance of each color of the X-Rite ColorChecker chart measured with a calibrated luminance meter was compared with the luminance value of the corresponding pixels extracted from the HDR image.

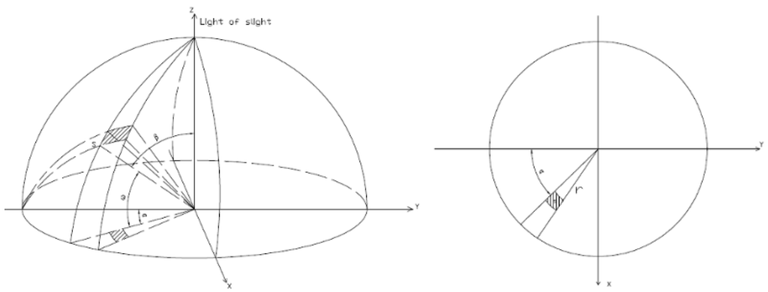

Fig. 3. The projection mode of fish-eye lens

2.3 Softwares

The multiple exposure photographs were processed using the free software Photosphere developed by Greg Ward who invented Radiance RGBE format[11]. All photographs were taken with the camera settings shown in Table 1. It is especially important to fix the white balance to Daylight for achieving consistent colour space transitions. Changing either the aperture size (f-stop) or the shutter speed (exposure time) can vary the exposure values. Shutter speed is a more reliable measure than aperture size. Therefore, exposure variations were achieved with a fixed aperture size (f/8.0), and varying only the shutter speed in manual exposure mode (2 s to 1/200 s).

Table 1. Nikon D60 camera settings

Featrue	Setting	Featrue	Setting
White balance	Daylight	Image	3872×2592
Lens	Fisheye	Aperture size	f/8.0
Exposure Mode	Manual	ISO	100

Photosphere can calculate camera response automatically[9]. Once the camera response curve is determined, Photosphere can fuse any photograph sequence into a HDR image. HDR images can be stored in image formats such as Radiance RGBE, where the pixel values can extend over the luminance span of the human visual system (from 10^{-6} to 10^{8} cd/m^2)[9].

The computational procedures to calculate the key parameters of glare evaluation were developed in Matlab.

3 Luminance Calculation

For analyzing the HDR images from Photosphere software, computational procedures were implemented (referred to as GetLuminance()). They allow the user to extract and process per-pixel lighting data from the HDR images saved in Radiance RGBE format.

CIE XYZ values for each pixel were quantified from floating point RGB values based on the standard colour space (sRGB) reference primaries, CIE Standard Illuminant D65, and standard CIE Colorimetric Observer with 2° field of view[9]. The transformation process is seeing in Ref .9, and transformation result is as follows:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2127 & 0.7151 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

So, we can calibrate images luminance with a physical luminance measurement of a selected region in the scene. This feature can be applied as a constant ('k') to the pixel values in an image [9]. Luminance (L) is calculated as:

$$L = k \times (0.2127 \times R + 0.7151 \times G + 0.0722 \times B)(cd / m^2) \tag{2}$$

4 Calculating the Key Parameters of Glare Evaluation

4.1 Detection of Glare Sources

Three principal methods were used for automatic detection of glare sources[3]:

1. Calculate the average luminance of the entire picture and count every section as a glare sources that is *x*-times higher than the average luminance;
2. Take a fixed value and count every section as glare sources that is higher than the fixed value;
3. Calculate the average luminance of a given zone (task area) and count every section as glare sources that are x-times higher than the average luminance of this zone.

The first method was implemented in the RADIANCE *findglare* tool. For very bright scenes only few parts or nothing could be detected, although the facade was obviously glare sources. Reducing the x-factor can increase the sensitivity to detect glare sources in a scene, but might lead to "over-detecting" potential glare sources in darker scenes.

The second method, which applied a fixed luminance value as threshold does not take into account eye adaptation. This method was therefore not considered to be a reliable method for lighting scenes with substantial luminance variations.

The last method was used in Wienold's new evaluation method for daylight environment[3]. Each pixel with a luminance value four times higher than the average task-zone luminance was treated as a glare source. This detection sensitivity factor can be changed.

In this paper, we use the first method to detect glare sources as same as RADIANCE. When the threshold is different, the detected result of glare is different. Reducing the threshold can increase the range to glare sources. The detected result is shown in Fig.5.

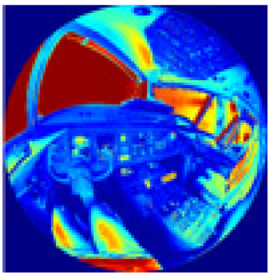

Fig. 4. The mapping of luminance in flight deck

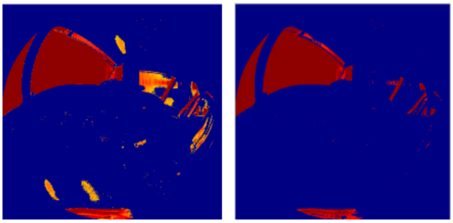

Fig. 5. Glare detected result of the flight deck

4.2 The Key Parameters of Glare Evaluation

In general, the glare evaluation draws upon the four physical parameters:

- The luminance of the glare source: the brighter the source, the higher the index;
- The background luminance: the general field of luminance controlling the adaptation levels of the observer's eye. The brighter the room, the lower the index;
- The position index: the angular displacement of source from the observer's line of sight. The further from the centre of vision, the lower the index;
- The solid angle: the larger the area, the higher the index.

Especially, the vertical eye illuminance is also considered as a primary factor influencing glare index in the DGP[3].

Source Luminance (*L_s*). The source luminance is the average luminance of all pixel of source. Through computational procedures in Matlab, luminance levels of HDR images from Photosphere can be obtained, see Fig.4. The luminance value of each pixel is obtained by the function "GetSourceLuminance ()". The average luminance of glare sources can be calculated through traversing all pixels of glare sources.

Background Luminance (*L_b*) . The background luminance is luminance of the field of view, not including source luminance, and called adaption luminance in some study. It can be calculated by

$$L_b = \text{total luminance} - L_s \tag{3}$$

It is obtained by the function "GetBackgroundLuminance ()".

Position Index (*p*). The position index of a source, *P*, is an inverse measure of the relative sensitivity to a glare source at different position throughout the field of view. There are two methods to calculate position index.

The first method is Guth position index, where is given by [6]

$$P = exp[(35.2 - 0.31889\alpha - 1.22e^{-2\alpha/9})10^{-3}\beta + (21 + 0.26667\alpha - 0.002936\alpha^2)10^{-5}\beta^2] \tag{4}$$

Where

α=angle from vertical of the plane containing the source and the line of sight, in degrees,

β=angle between the line of sight and the line from the observer to the source.

Through the new study, Iwata[5] found that sensitivity to glare caused by a source located below the line of vision is greater than sensitivity to glare caused by a source located above the line of vision. Then, a new method to calculate the position index was developed; it could be expressed by this equation [3,4]:

$$P = 1 + 0.8 \times R / D \quad (R < 0.6D)$$
$$P = 1 + 1.2 \times R / D \quad (R \geq 0.6D) \tag{5}$$
$$R^2 = H^2 + Y^2$$

Where

R=distance between source and fixation point (m),

D=distance from eye to vertical plane on which a source is located (m),

H=vertical distance between source and fixation point (m),

Y=horizontal distance between source and fixation point (m).

In this paper, Guth position index is used above the line of vision, and the new position index of Iwata is used below the line of vision. The position index of each pixel is obtained by the function "GetPositionIndex()". The mapping of position index is shown in Fig.6.

Based on the equisolid projection mode of fish-eye lens, the meaning of α、β is shown in Fig2.

Where, β=π/2-ω=π/2-2arcsin(r/2f), r is the distance between the centre of a circle and the a source, f is the focus of lens.

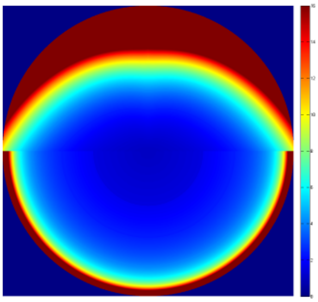

Fig. 6. The mapping of position index[5]

Solid Angle of Source (*Ω*). Solid angle (*Ω*) is a measure of that portion of space about a point bounded by a conic surface whose vertex is at the point. It is defined as the ratio of intercepted surface area of a sphere centered on that point to the square of the sphere's radius. It is expressed in steradians[6].

For the fisheye used equisolid projection mode, solid angle is given by the following equation:

$$\Omega = s/f^2 \tag{6}$$

Where, s is the area of source pixel, f is the focus of the lens.

The solid angle of each pixel is obtained by the function "GetSolidAngle()".

Vertical Eye Illuminance (E_v). The vertical eye illuminance can be calculated by the equation:

$$E_v = \sum_{i,j}^{n} L(i,j) \times \Omega(i,j) \tag{7}$$

Where, L is the luminance of pixel, Ω is the solid angle of pixel.

It is obtained by the function "GetVerticalEyeIlluminance ()".

5 The Glare Evaluation

So, we can evaluate the glare of existent flight deck. Now, DGP is utilized as an example to evaluate the glare for daylight in glare quantifiable evaluation of flight deck shown in Fig.4. The observe position is the design eye position of pilot, and observe direction is the horizontal direction.

The DGP equation is

$$DGP = 5.87 \times 10^{-5} E_V + 9.18 \times 10^{-2} \log_{10}(1 + \sum_i \frac{L_{S,i}^2 \omega_{S,i}}{E_V^{1.87} P_i^2}) + 0.16 \tag{8}$$

Where DGP is Daylight Glare Probability; E_v is the vertical eye illuminance (lux); L_s is the luminance of source (cd/m^2); ω_s is the solid angle of source; p is the position index of the source.

Aiming to the flight deck scene shown in Fig.4, the calibration factor is 371.471. The detection threshold luminance of the glare sources which is 1273 cd/m^2 is four times higher than the average luminance which is 318.2587 cd/m^2. The vertical eye illuminance E_v is 885.3243 lx. The solid angle of each pixel for glare sources $\omega_{s,i}$ is 8.25×10^{-7} Sr. The position index P_i is shown in Fig.6.

The calculation result of DGP is 0.2483, which express that only 24.83% people feel fidget and discomfort. So, in this condition, the most people are comfort.

6 Conclusions

Several glare indices based on current method cannot be utilized to evaluate non-uniform glare, irregular shape glare and indirect glare correctly. In this paper, using digital camera to evaluate glare offers a simple method. Digital camera's imaging luminance measurement is based on High Dynamic Range (HDR) image processing. The computational procedures to calculate source luminance, background luminance, position index and solid angle of source, to detect the glare sources were developed in

Matlab. After calculating source luminance, background luminance, position index, solid angle of source, the desired glare index can be computed. Finally, Daylight Glare Probability (DGP) equation is utilized as an example to evaluate the glare for flight deck in daytime. The results indicate that the proposed methods are convenient for evaluating the visual performance and comfort in human-computer of flight deck.

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