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INFRA-RED RADIANT INTENSITY EXPOSURE SAFETY STUDY FOR THE EYE TRACKER

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ABSTRACT

With any device that is used to record or evaluate biosignals, it is in the inventor's interest to determine how that device withstands a rigorous examination in regards to its inherent safety during use. For this, a Risk Management (Hazard) Analysis is a useful exercise. With this in mind, the most probable hazard concerning the Eye Tracker System (a device used to measure saccadic eye movements utilizing Reflective Differencing of Infra-Red light) is the exposure effect to the human eye caused by the Radiant Intensity of the IR emitters mounted on the Head Mounted Transducer.

Presented in this article are the results of a study used to determine the Radiant Intensity exposure of the Eye Tracker as designed. Comparing these results with accepted norms for Radiant Intensity exposure, a redesign of the Head Mounted Transducer is detailed with results given showing that this new transducer fits safely into the accepted norms of Radiant Intensity exposure. Presented are the mathematical calculations used for the initial study and the redesign.

Presented also in this paper is an internal noise abatement study performed on the Eye Tracker and the steps taken to reduce this noise. Compared results before and after the study are also presented.

INTRODUCTION

With any device that is used to record or evaluate biosignals, it is in the manufacturer's/inventor's interest to determine how that device withstands a rigorous examination in regards to its inherent safety during use. For this, a Risk Management (Hazard) Analysis is a useful exercise.

When performing a Risk Management (Hazard) Analysis, a group of individuals, some well-versed in engineering, others in perhaps nursing or other clinical background, as well as other laymen, together as a group determine how the device could adversely affect the user and the subject. All concerns with respect to the efficacy of the new device brought up by this group are addressed, regardless of the probability of any one particular event happening. Proper addressing of concerns details how each "risk" or "hazard" is accounted for and circumvented during the engineering cycle of the device. Risks and hazards not capable of being properly addressed force the device to be re-engineered in such manner to prevent the hazard.

The most obvious probable risk concerning the Eye Tracker System [1] is the exposure effect to the human eye caused by the Radiant Intensity of the IR emitters mounted on the Head Mounted Transducer. Following is a brief detail on how this concern is addressed theoretically and mechanically with respect to the original design and a redesign.

METHODS

Sliney and Wolbarsht state that the ACGIH TLV has proposed a limitation on IR-A and IR-B infrared radiation beyond 770 nm to 10 mW/cm^2, [2] (since accepted). This value has also been described as to what the eye is exposed to on a cloudless day. Also, ANSI standard Z136.1 can be used as a guideline to IR-A exposure hazard, but this standard concerns itself mainly with laser light. Designers of this particular type of equipment (i.e. the Eye Tracker) tend to follow a rule of thumb wherein a maximum exposure of 2 mW/cm^2 is considered a safe exposure for long exposure times. This limit has a safety factor of 5 over what ACGIH TLV considers safe.

The Eye Tracker as originally designed utilized four Agilent Technologies HSDL 4420 emitters, two on each eyepiece side. These emitters operate at 875 nm, have an approximately 30 degree beam spread, and an Radiant On Axis intensity of 32 mW/steradian (mW/sr) at a delivered current of 100 mA.[3] As per design, these emitters are situated 2 cm from the surface of the eye.

To determine the radiant intensity exposure, it is first required that we calculate the size of the exposure area in steradians (square radians). Examining the figure below (Fig 1.), it is noted that one steradian of IR light (sr, 57.3 $degrees^2$) regardless of the steradian radius will bathe the entire eyeball. However, there are limiting factors such as the eyelid, etc., therefore it is graphically suggested that the parts of the eyeball that are bathed in IR light ranges only 40 degrees.

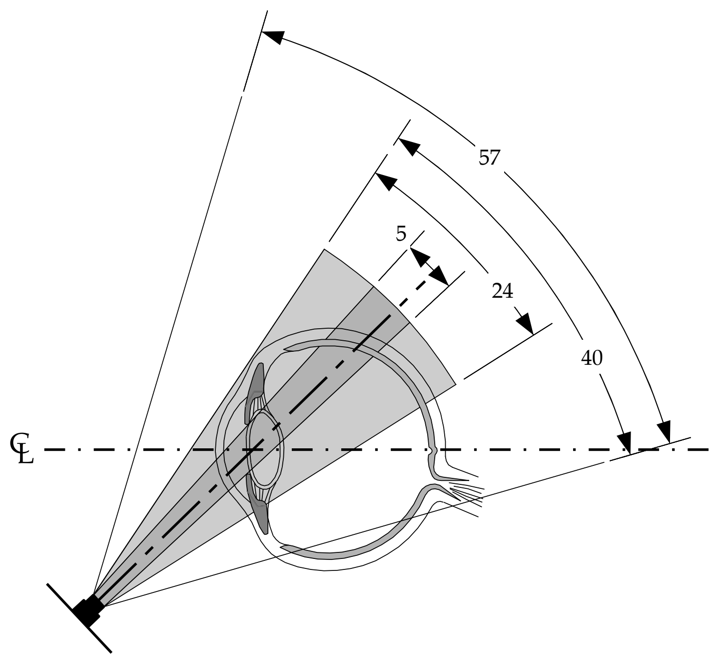

Figure 1: Cross-section of eyeball depicting angular coverage of emitter optoelectronics (represented by dark shape at lower left). Emitter and eyeball shown to scale with respect to each other and location as mounted in transducer. (Visio 2000 – Author's rendition)

Since the emitter is rated to have a 32mW/sr radiant intensity, but only 40 degrees of the beam spread contact the surface of the eye, then;

$$40°(.01745) = .698\,radians \qquad \text{(eq.\#1)}$$

where .01745 is a conversion factor to derive radians from degrees., Then;

$$.698\,radians = .487\,square\ radians\ (sr.) \qquad \text{(eq.\#2)}$$

Multiplying this times the radiant intensity yields (in a manner to determine how much intensity reaches the delicate parts of the eye):

$$[.487\,square\ radians(sr.)]\left(32\frac{mW}{sr.}\right)=15.584\,mW \qquad (eq.\#3)$$

Therefore, the 40 degree section of the eyeball as illustrated is exposed to 15.584 mW radiant power. (This could be considerably higher since the beam angle of the HSDL 4420 is less (at 30 degrees) that the 40 degree area considered.

Since the standard has units of mW/cm^2, it must be determined how many square centimeters are within 40 degrees. In this case, as with the design, we consider the steradian to have a radius of two centimeters and therefore an area of 2 cm^2. A simple ratio of area shows that the 40 degree area is .974 cm^2 (see Eq. 4 below). Another ratio is applied and it is found that each emitter exposes the eye to 16 mW/cm^2 of radiant intensity (see Eq. 5 below).

$$\left(\frac{2\,cm^2}{1\,rad}\right)=\left(\frac{x}{.487\,rad}\right)=.974\,cm^2 \qquad (eq.\#4)$$

$$\left(\frac{15.584\,mW}{.974\,cm^2}\right)=\left(\frac{x\,mW}{cm^2}\right)=16\frac{mW}{cm^2} \qquad (eq.\#5)$$

However, there are two emitters for each eye, therefore the radiant exposure to each eye is twice that of Eq. 5 whereon the exposure per eye will be 32 mW/cm^2. This is clearly higher than the safety standard of a bright sunny day with 10 mW/cm^2 exposure allowed.

Sliney also introduces an example of an IR reflective eye movement monitor and uses the following calculations to determine if the device is safe to use [4] wherein he compares a Source Radiance (L) with a Source Radiance Hazard L(Haz). Utilizing Sliney's equations with our originally designed device wherein the emitter has an Intensity rating of 32 mW/sr and the source size (as determined in device data sheets) has a diameter of 1.65 mm (area equal to .0272 cm^2), then,

$$L=I/A_s \qquad (eq.\#6)$$

$$L=\left(.032\frac{W}{sr}\Big/.0272\,cm^2\right)=1.176\frac{W}{cm^2\cdot sr} \qquad (eq.\#7)$$

$$L(Haz)=\left[\frac{.06}{\alpha}\right]\frac{W}{cm^2\cdot sr} \qquad (eq.\#8)$$

where

$$\alpha=\left[\frac{Point\,Source\,Diameter\,(D_L)}{Viewing\,Distance\,(V_D)}\right]=\left[\frac{.165\,cm}{2\,cm}\right]=.0825 \qquad (eq.\#9)$$

Therefore

$$L(Haz) = \left[\frac{.06}{.0825}\right]\frac{W}{cm^2 \cdot sr} = .727\frac{W}{cm^2 \cdot sr} \qquad (\text{eq.}\#10)$$

Clearly the Source Radiance (L) of the originally implemented emitters (1.176) is larger then the allowable hazard Source Radiance of .727. These emitters would not be safe to use.

Different emitters were utilized to try to improve on this situation. (These emitters have the same source size, etc.) These new emitters, HSDL 4400 also operate at 875 nm, but have a 110 degree beam spread and have a 3mW/sr intensity at 50 mA.[5] Using the same general calculations given that the same 40 degree pocket is used, we have;

$$[.487 \, square \ radians(sr.)]\left(3\frac{mW}{sr.}\right) = 1.461mW \qquad (\text{eq.}\#11)$$

$$\left(\frac{1.461mW}{.974cm^2}\right) = \left(\frac{x \, mW}{cm^2}\right) = 1.5\frac{mW}{cm^2} \qquad (\text{eq.}\#12)$$

(The amount that reaches the delicate part of the eye)

As before, there are two emitters for each eye, therefore the radiant exposure to each eye is twice that of Eq. 12 whereon the exposure per eye will be 3.0 mW/cm^2. This is slightly above the "rule of thumb" safety standard but lower than that of a bright sunny day with a standard of 10 mW/cm^2 exposure allowed.

Examining the Source Radiance Hazard with these new devices we have;

$$L = \left(.003\frac{W}{sr} \Big/ .0272cm^2\right) = .110\frac{W}{cm^2 \cdot sr} \qquad (\text{eq.}\#13)$$

and

$$L(Haz) = \left[\frac{.06}{.0825}\right]\frac{W}{cm^2 \cdot sr} = .727\frac{W}{cm^2 \cdot sr} \qquad (\text{eq.}\#14)$$

It can be seen that the Source Radiance (L) of .110 is clearly lower than the Source Radiance Hazard L(Haz) of .727. It can be safe to say that these emitters are OK to use.

In defense of the new design, Sliney has stated that if a diode is safe to view, then it is certainly safe to view if some of the total energy emitted each second were removed from the beam [6]. In the Eye Tracker, the emitters are actuated at 5000 Hz. with a duty cycle of 50 percent. Therefore the emitters are "on" for only half of the time. Therefore, it can be said that the total radiant power exposure on each eye is only 1.5 mW/cm^2. Considering the 10 mw/cm^2 standard, these new devices are safe to use, and they are within the limits of the 2 mW/cm^2 "rule of thumb' and Sliney's Source Radiance Hazard.

RESULTS

Subsequent to the installation of the new emitters (the HSDL 4400 emitters), and under University of Connecticut IRB control, a number of subjects (including this author) have "worn" the Head Mounted Transducer for periods approaching one hour. There have been no adverse affects – to that matter no affects at all with respect to overexposure of the eyes to the emitted Radiant Intensity, there has been no report of "dry eyes" during or after use as well as no report of after images. As an interesting aside, all subjects have reported seeing the dull red "tails" of the emitters – but this is of no harm. It is noted that the subsequent "powering down" of the IR reflectance in general due to these new emitters does not decrease the sensitivity of the device.

CONCLUSIONS

Presented had been a simple method to determine the level of Radiant Intensity Exposure and to determine if said exposure is not acceptable for safe use. Using the same equations, the designer/researcher/builder can supplement other optoelectronic designs and determine if these operate under within safe parameters. As seen with the original design of the Eye Tracker, it is determined that the emitters used at that time would have been far too intense for safe use, installation of the new emitters now operate within safe parameters as described by this paper.

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