Sensors and Actuators A 148 (2008) 388–394

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Class I infrared eye blinking detector

Fabio Lo Castro

CNR-Institute of Acoustics, Via del Fosso del Cavaliere 100, 00133 Rome, Italy

ARTICLE INFO

Article history:
Received 12 March 2008
Received in revised form 21 July 2008
Accepted 2 September 2008
Available online 10 September 2008

Keywords:
Infrared
LED
Blinking
Safety
Eye
Detector

ABSTRACT

Eyes blinking detectors are often used to monitor the drowsiness or the fatigue during any activity. Therefore, sensor has to be as safe and less intrusive as possible in order to avoid additional annoyance and hazards. The proposed detector has been developed according to the Class 1 specifications of IEC 60825-1 standard on the safety of LASER and LED products in order to work until 8 h in a safety condition for the user. The sensor used is a commercial infrared emitting diode coupled to an infrared photodiode, embedded in the same device and usually used for data link, clipped on the rod of the glasses and placed closed to the eye. The sensor uses the technique of the modulation of the infrared beam to be less sensitive to the head movements and changes of environmental light. Actually a cable connects the sensor to the control board that sends the eye blinking signal to a personal computer in order to be recorded.

1. Introduction

Eyes are a good candidate to be monitored in order to recognize the fatigue or the disease of a person. In particular the eye lid, the pupil and the gaze can be observed.

Different technique and methods can be used, as electrooculography (EOG), electromyography (EMG), infrared-oculography (IR-OG) and image based methods called video oculography (VOG) [1,2]. Each one of these has its advantages and disadvantages.

The last two methods require an infrared source as LEDs. Although, in the last years LEDs and IR-LED were considered safe on the contrary of lasers, today this is not still true considering their high non-tolerable irradiance.

Thus according to the standard IEC 60825-1, regarding the eyes safety, we have developed an infrared eye blinking detector that can be considered safe.

This paper will describe how it is possible to develop a safe eye blinking detector, the choice of the rules to make it safe and the evaluation of its level of eyes safety.

1.1. Eye movements

Eyelid movement is one of the visual activities that reflects a person's level of fatigue.

There are two principal ocular measures that characterize the eyelid movement. The first one is the percentage of eye closure over time (*PERCLOS*) [3] and the second one is the average eye-closure speed (*AECS*), i.e. the amount of time needed to fully close or open the eyes. PERCLOS is the most valid ocular parameter for monitoring fatigue and it is evaluated computing the cumulative eye-closure duration over time, excluding the time spent on normal eye blinks. In literature the eye blink is defined as a closure followed by an eye opening within a period of 1 s [4]. The degree of eye opening is characterized by the shape of the pupil. It is not always the same but changes getting more and more elliptical as soon as the eyelids start to close the eyes.

There are two types of eyes blinks: voluntary eye blink and spontaneous eye blink.

The voluntary blinking is a very rapid movement; it takes only 0.2 s, about half of the time taken by spontaneous blinking [5].

The spontaneous blinking is the most frequent movement of the eyelid. It consists in rhythmic involuntary closing and opening, at a rate of 10–30 movements per minute depending principally on his activity and health state [6]. The whole movement (opening and closing) lasts 0.3–0.4 s and it is repeated after an interval of 2–10 s. Slow-camera cinematography shows that upper lid falls like a curtain; the lower lid remains almost motionless.

Spontaneous blinking is an indicator of fatigue, increasing its rate, while we spend time watching a display [7], like a TV or a monitor, reading [8] a book or while we are driving [9].

Furthermore it gives information about the presence of disease as Parkinson syndrome [10], stroke [11] and others nervous system diseases [12]. In the first case it is commonly found a slow blinking

E-mail address: fabio.locastro@idac.rm.cnr.it.

0924-4247/$ – see front matter
doi:10.1016/j.sna.2008.09.005

rate while in the other cases there is frequently a high blinking rate during resting.

Gaze has the potential to indicate a person's level of vigilance, finding a narrow gaze in fatigued individual.

1.2. Ocular measurement techniques

Traditional methods to record the eyes blink signal are the EOG and the EMG.

EOG uses three silver/silver chloride or gold electrodes placed on the skin, up and down the eye, for measuring the voltage difference between the cornea and the fundus, that is directly related to the eyes movement and the blinking. Also the EMG uses electrodes to catch signal from muscles close to the eyes.

Those two methods present different problems regarding the electrodes. In fact they could detach from skin during session, for example if a person is sweaty, or they could have a bad contact, increasing the impedance of the electrode and causing a low signal to noise ratio. Furthermore the electrode or the plaster that hold up the electrode could cause local irritation or could disturb the person during his activity.

At last the movement of the person can cause artefacts in the signal.

To avoid these problems new methods as the IR-OG and the VOG have been developed. They are contact free and non-intrusive and for these reasons are more and more used to detect the fatigue, especially during driving.

IR-OG is based on the principle that if a fixed light source is directed against the eye, the amount of light reflected back to a fixed detector changes with the pupil position and if the eye is open or closed.

This principle has been exploited in a number of commercially available eye trackers used also on the animals [13–18].

The infrared light is used because it is invisible to the eye, and does not distract the subject (driver).

As infrared detectors, that are sensible only to the infrared wavelength, are not influenced by other light sources, as the bulb or fluorescent lamp (having them a precise working frequency) or the ambient lighting (if it changes slowly).

The IR-OG usually is used for measuring horizontal rather than vertical eye movements and it is able to achieve spatial resolutions (the size of the smallest movement that can reliably be detected) in the order of 0.1° and temporal resolutions of 1 ms or more.

The disadvantage is that during horizontal and vertical measurement blinks can be a problem, not only because the lids cover the surface of the eye, but also because the eye retracts slightly after the blink, altering the amount of light reflected for a short time. But if we are interested only on the eyelid movement this is not an inconvenient. The advantage of the IR-OG method is that it is portable, wearable and cheap compared to the previous system. The only precaution that has to be taken is on the angle between the IR emitter and detector, because it is vital for the detector in order to receive the signal reflected back from the eye.

The VOG usually uses a video camera and software for the eyes tracking and blinking evaluation [3,19] in order to evaluate the blinking rate and also the gaze direction. The direction of a person's gaze is determined by two factors: the orientation of the face (facial pose) and the orientation of the eye (eye gaze). Facial pose determines the global direction of the gaze, while eye gaze determines the local direction of the gaze. Global and local gazes together determine the final gaze of the person.

In order to find the pupil and retina on the picture the VOG systems use an infrared spot to lighten the retina so that it can be easy identified.

Table 1
Eyes pathologies related to the infrared and other exposed radiation wavelength

Spectral region	Eye	Skin
Ultra-violet C (180–280 nm)	Photokeratitis	Erythema (sunburn) Accelerated skin ageing process
Ultra-violet B (280–315 nm)		Increased pigmentation
Ultraviolet A (315–400 nm)	Photochemical cataract	Pigment darkening
Visible (400–780 nm)	Photochemical and thermal retinal injury	Photosensitive reactions
Infra-red A (780–1400 nm)	Cataract, retinal burn	Skin burn
Infra-red B (1.4–3.0 μm)	Aqueous flare, cataract corneal burn	
Infra-red C (3.0 μm–1 mm)	Corneal burn only	

The advantage of the image based method is that it leaves completely free of movement the subject, but he has to be in front of the camera, otherwise the camera has to be put on the head of the subject.

The inconvenience is that it has a low resolution, due a frame rate, and requires a heavy image recognition software and hardware.

2. Eyes hazard

Both the IR-OG and VOG considered above emit an infrared light that is pointed toward the eyes, that is not visible, hence not blinding and not giving disturbance that cause the closure of the eyes. Furthermore the emitter is located at a distance, that can change from 0.01 to 1 m (according to the type of eyes movements detector) and it could work for different hours.

These considerations point out situations that could be dangerous to the eye. In fact being the crystalline transparent to the near infrared light, it arrives directly on the retina and could cause injury or burn as shown in Table 1 [20].

This mean that the irradiance that arrives to the retina is in the order of 100k times greater than that on the cornea [21], considering 7 mm the diameter of the pupil (worst case, young eye completely dilated) and the pupil corresponding image between 10 and 20 μm in diameter. Hence an irradiance of $1\,\mathrm{W\,m^{-2}}$ at the cornea level becomes $100\,\mathrm{kW\,m^{-2}}$ on the retina. Other wavelengths that do not go through the crystalline could cause cataract or corneal irritation.

The amount of energy absorbed by the tissue changes with the wavelength of the light and the tissue itself. It could cause burns, lesions and temporary or permanent loss of vision, depending on the magnitude of the exposure. On the contrary, the skin tolerates the exposition to radiation better than the eye.

The hazard is virtually independent of the distance between the source and the eye in case of point or extended source with a well collimated beam, as a LASER.

In case of a point-type and diverging beam source, as a LED, the hazard increases with decreasing distance between the beam source and the eye. This is true until distance is greater than the shortest focal length. Thus for distance less than the shortest focal length there is a rapid growth of the retinal image and a corresponding reduction of the irradiance, even though more power may be collected.

2.1. Safety evaluation

Different studies on the hazard assessment and the reactions of the human tissues to the laser radiation have developed different standard in different country, but often they have in common the