Computer Vision Syndrome prevention using real-time accurate Blink Detection

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Abstract

Computer Vision Syndrome (CVS) is a common problem among computer users. Staring at an object from two feet for a long time will make the eye dry and cause eye strain and fatigue. Most of the computer users suffer from headaches, loss of focus, burning eyes, and blurred vision during their long time work in front of a computer monitor. In this paper a computer vision software solution (CVSS) to CVS is proposed to decrease these symptoms and prevent dry eye effect. CVSS traces user eyes in real time, through a simple low resolution web cam, that exists in most modern computers and laptops. No special hardware or configuration is required to use this software. The system counts eye blinks and logs their durations and warns user to blink regularly thus avoiding dry eye. It also tracks user's blink frequency and other parameters to warn the user about drowsiness and exhaustion of the eye or collect this information for oculists. Experiments show that the system can detect and analyze blinks in real time with low false- positives and very low false-negatives and it succeeds in increasing users blink rate through various notification methods.

Keywords: computer vision syndrome, dry eye, blink detection, facial features tracking, computer vision.

1 Introduction

Computers are inseparable part of modern life of humans in the present days. Desktops, laptops, game consoles, etc. are all examples of devices with visual display terminal (VDT) that cause various health problems complain. Most common complains are related to eyes, problems such as eyestrain, irritation, tired eyes, redness, eye dryness, blurred vision and double vision. These visual problems are referred to as Computer Vision Syndrome (CVS) in medical science [1].

Various research works target treatments and prevention methods for CVS [2][3]. Although this syndrome is not causing permanent damage to the eye, the symptoms effectively decrease users' efficiency and even influence quality of life. It has been shown that ergonomics problems such as display height, illuminations, etc. are causing CVS but even with good quality and well positioned displays, such as ones in modern notebooks, the syndrome is still observed. In addition, it has been shown that CVS is closely related to user eyes blink frequency [4] that controls amount of tear on the surface of the eye [5].

Computers have helped disabled or sick people in various applications and this time it can be use to prevent a syndrome created by it, itself. To prevent this syndrome, a computer vision software solution (CVSS) is proposed in this paper. CVSS recognizes and tracks facial features especially from eyes to prevent dryness of the eyes. Most applications of facial features tracking are in Human Computer Interactions (HCI) such as in [6], [7], and [8].

The first step of the proposed method is to detect and track eyes. Many algorithms are designed to detect eyes. Some algorithms first detect user's face and then detect eyes by using pre-defined location of them. Some other algorithms detect eyes directly through preset templates. After detecting eyes, the next step is to detect their blink that can be done by matching templates or examining differential image. Eye blink detection have many applications such as Driver Drowsiness detection [9], doze alarm [10], and Gaze Tracking System [11].

After detecting the eye and eye blinks it is desirable to log blinks and their durations and incorporate this information to prevent dry eye. Various CVSS methods are proposed to prevent eye blink frequency, dropping below a threshold and thus prevent dryness and fatigue of the eyes. There are three solutions to help users deal with CVS. A short term solution tries to remind user to blink regularly and thus make blink frequency steady. A medium term solution suggests the user to rest on low blink frequency. Finally, a long term solution logs user's blinks to be analyzed by an oculist or by the user herself at a later time.

The rest of this paper is organized as follows. In Section 2 computer vision syndrome and dry eye are defined. Section 3 includes a brief background and recent related work on eye blink detection. The proposed method is described in Section 4. Section 5 shows the result of the system and finally Section 6 concludes the paper and proposes future work.

2 Computer Vision Syndrome

Computer Vision Syndrome is defined as "the complex of eye and vision problems related to near work which are experienced during or related to computer works." [12]. This ten years old definition is criticized by Yan et al. [1], as it lacks at least two important aspects of CVS. First, CVS symptoms are vision-related (e.g. headache and neck pain) rather than vision specific. Second, near works with computer is not the only cause of CVS. As observed in other research [13] long time computer usage and ergonomics problems are two other most important causes of CVS.

During a long time work with VDTs (video display terminal or visual display terminal) blink rate is reduced. In [14] Yaginuma et al. studied the relation between blink frequency and lacrimation (the secretion of tears). When frequency of blinks decreases, the lacrimation is also decreased and the abnormally in tears volume and tear layer size make the eye dry and strained.

CVS symptoms are classified into four categories [4]:

- **Asthenopic**: such as eyestrain, tired eyes, sore eyes and dry eyes.
- **Ocular surface related:** such as watery eye, and irritated eyes, contact lens problems.
- **Visual:** including blurred vision, slowness of focus change, double vision, presbyopia, and sense of a foreign body presence in the eye.
- **Extraocular:** including neck pain, back pain and shoulder pain.

Although CVS has not been proven to cause any permanent damage to the eye, it is a common syndrome among computer users. First three symptoms of CVS are visual related and they mostly result in dryness of the eye also known as Dry Eye.

2.1 Dry Eye

Dry eye is the most common symptom of CVS Resulted from reduced blink rate in VDT users. Dry eyes can be resulted from an improper balance of tear production and drainage. Tears are produced by several glands in and around the eyelids. Environmental conditions such as wind and dry climates can affect tear volume by increasing tear evaporation. When the normal amount of tear production decreases or tears evaporate too quickly from the eyes, symptoms of dry eye can develop. Although the only reason for dry eye is not computer usage and it is a known disease because of different environmental and internal conditions, people using a VDT have demonstrated a higher probability of eyestrain and ocular pain and suffer more from this symptom [15].

Tears are made up of three layers (Figure 1): oil, water, and mucus. Each component serves a function in protecting and nourishing the front surface of the eye. A smooth oil layer helps to prevent evaporation of the water layer, while the mucin layer functions in spreading the tears evenly over the surface of the eye. If the tears evaporate too quickly or the eye is left open for a long time dry eye symptoms can be observed.

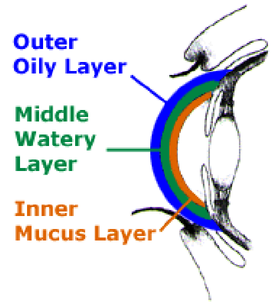

Figure 1 – three protection layer made by tears after a normal blink.

2.2 Eye Blink and tear dynamics

Normal blinking is an essential involuntary action for the protection of the ocular surface. Under relaxed conditions without any tasks, people blink every 3 to 4 s to maintain a moistened ocular surface. When the ocular surface is desiccated by irregularities such as excess wind or dry eye-related diseases, the blink rate is increased to compensate for the lost moisture.

Effect of blinks has been studies in [16] and [5]. Blinking plays an important role in the distribution and drainage of tears and helps in maintaining equilibrium of the tear volume on the ocular surface and in the conjunctival sac. It also plays a critical role in periodic renewal of the preocular tear film. Any alterations in the blinking pattern may affect tear distribution and drainage, leading to changes in the tear volume and other tear system parameters. Research shows that on delayed blinks, balance between tear secretion and the loss become altered.

To ensure adequate wetting, it appears that during the normal blinking process, a dynamic balance is maintained with minimal changes in tear volume on the ocular surface. During delayed blinking, this balance is altered due to reflex tearing and possibly decreased drainage, which was found dependent on blink frequency. With frequent blinks, a full coverage of the ocular surface with tear film is maintained during the open-eye period, and the ocular surface is protected. Tear film thickness varies over time, with thinning during inter-blink intervals and thickening after blinks.

2.3 CVS Prevention and Treatments

Dry eyes can be diagnosed through various drugs [2]. But Dry eyes resulted from CVS can be prevented easily with some practices. These practices can also diagnosis this type of dry eye because CVS does not prove to have permanent damage to the eye. Oculist recommendation for computer users is to blink frequently and regularly during works with VDTs. This will make the glands in and around the eyelids to make tears and wet the eye surface. This simple exercise proved to be very effective in preventing and treatments of dry eye. There is a rule to prevent dry eye named 20/20/20 rule as suggested by clinical optometrists [17]. That is, every 20 minutes of computer use, stare at something 20 feet away at least for 20 seconds. Several computer programs have been developed to help users follow these rules but they seems to be inefficient because of lacking any input from the user (they commonly display a pop-up window every twenty minutes, regardless of there is a user in front of computer or not). There is also another criticism to these programs or to the rule itself. Eye exhaustion and dryness depends on the user's eye strength, work habits, and heaviness of the work. The dryness and exhaustion of the eye is not the same for watching a film or doing a heavy data entry in a data-sheet. Lack of the input from user's eyes makes this rule incapable of efficiently preventing dry eye. More intelligent software and methods with some information from the user's habits in blinking need to counter this problem.

3 Eye Blink Detection Background

Eye is one of the fundamental features of the face in detection and tracking algorithms. It is used for detecting the whole face as well as its position and other facial feature positions. Various methods are available for detecting eyes and their blinks. The most important factor in designing these methods is execution speed, because most of the times, a real-time algorithm is demanded.

Betke et al. [18] proposed a real time blink detection method based on image difference and connected components labeling. This method computes frame difference in a sequence of images that is captured from a webcam. In the difference image, the method tries to locate two eclipse-like shapes that are candidates for eye blinks. After candidates are selected for blink, more restrictions may apply to select best candidate.

For performance reasons, after the eye is located by the above method, two samples from left and right eye are captured and then user's eye is tracked using a simple tracking method. This method is shown to be acceptable for real time applications, but its accuracy and time complexity may not be good enough for the purpose of this paper's application.

A more precise but relatively slower approach to eye detection is presented in [19] based on second order change detection. Allow the results of this work show high accuracy, it is not applicable for the purpose of this work, due to its time complexity.

3.1 Integral Image

Integral image is a technique that is used in [20] to compute rectangle features. It is an intermediate representation for the image that. At each point *x, y* integral image contains the sum of pixels in the rectangle *0, 0, x, y* (top-left corner of the image to *x, y*). It can be shown by equation (1).

$$ii(x, y) = \sum_{x' \le x, y' \le y} i(x', y') \qquad \text{(eq. 1)}$$

where $ii(x, y)$ is the integral image and $i(x, y)$ is the original image. The authors proposed a method to compute integral image in one pass using cumulative row sum:

$$\begin{aligned} s(x, y) &= s(x, y-1) + i(x, y) \\ ii(x, y) &= ii(x-1, y) + s(x, y) \end{aligned} \qquad \text{(eq. 2)}$$

where $s(x, y)$ is the cumulative row sum, $s(x, -1)=0$ and $ii(-1,y)=0$.

Using the integral image, one can compute the sum of pixels within any rectangle in the image with only four array references (see Figure 2).

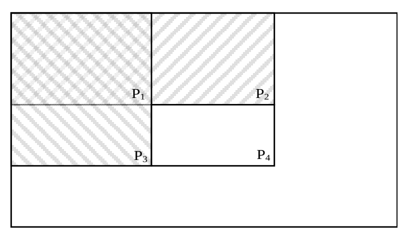

Figure 2 – to compute sum of pixels in white box, subtraction of $ii(p_4)$ from hatched section, that is $ii(p_2)$ plus $ii(p_3)$ minus $ii(p_1)$, should be computed.

4 Proposed Method

The method in this paper consists of two steps: step one is real time detection of eye blinks and tracking user eyes; and step two is incorporating blinking data to prevent dry eye by appropriate warning messages. The proposed method combines two methods in [20] and [18] to reach good accuracy and speed in real time blink detection while it uses recommendations from optometrist research in [13] and [17] to prevent and treat Dry Eye.

4.1 Real Time Blink Detection

Detecting eye blinks is among the easiest facial feature detection methods, but the speed of this detection is sometimes challenging. For the purpose of this paper the algorithm should not only be real-time but also utilize the CPU cycles as low as possible because the goal of this system is to work along other system applications in a normal PC station or notebook computer.

The proposed algorithm mixes the idea in different research projects on facial feature detection. The idea of integral image is applied to differential image between two adjacent frames. Furthermore, after detection of an eye blink, the eyes are tracked using a simple tracking method to speed up the process of future detections. A fast binary median filter is also implemented that has good result in one pass.

4.1.1 Integral Image computation

A novel algorithm is proposed to compute integral image in one pass with less memory complexity and easier implementation. The algorithm uses integral image computed so far to compute new values as in equation 3.

$$ii(x,y) = i(x,y) + ii(x-1,y) + ii(x,y-1) - ii(x-1,y-1) \qquad \text{(eq. 3)}$$

where $ii(x, y)$ is the integral image, $i(x, y)$ is the original image, $ii(x, -1)=0$ and $ii(-1,y)=0$.

4.1.2 One-pass Fast Median Filter

Webcam images have too many noises that prevent the algorithm to detect eye and blinks precisely. Experiments with various filters show that Median filter is a good candidate to reduce these noises. But commutation cost of this filter makes it inapplicable for real time (thirty frames per second). To compute Median filter fast enough for this application, the fact that all points are threshold and thus a binary median filter is adequate, is taken into account and a fast algorithm is designed for this filter.

To compute the result of the filter in one pass, sum of three columns of last mask values is stored in three variables c_1, c_2, and c_3 as in equation 4:

$$\begin{aligned} s &= s - c_0 \\ c_0 &= c_1; c_1 = c_2; \\ c_2 &= t(x,y) + t(x,y-1) + t(x,y-2) \\ s &= s + c_2 \\ t(x-1,y-1) &= \begin{cases} 0 & s < 5 \\ 1 & s \ge 5 \end{cases} \end{aligned} \qquad \text{(eq. 4)}$$

Also, the sum of all pixels in mask is stored in a variable called s. At each step, the value of c_1 (last column to be go out from mask) is subtracted from s and new column value is computed in c_2 after shifting c_i variables to left. Then the new value of c_2 is added to the sum. Center pixel of the mask is, then, updated according to the sum of pixels in the mask (s). Results show that the above algorithm is at least three times faster than a simple binary median filter. An example of the results of this method is shown in Figure 3.

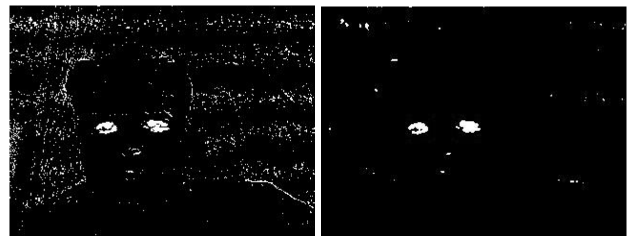

Figure 3 – One pass Fast Median filter result. Left image is noisy threshold difference image and Right image is the result of Proposed Fast Median Filter.

4.1.3 Blink Detection

A blink can be considered as two big dots of changes with the same size and with a defined distance (at least proportional to dots' size). To detect such a change in differential image, the mask in Figure 4 and score computation in equation 5 is used. When a blink occurs, there are some changes on the eyes position that can be seen in the threshold differential image. Also there is nearly no change in other region of face, or at least in the region near the eyes when blinks happens. By using this information, a rectangular mask is used to detect blinks.

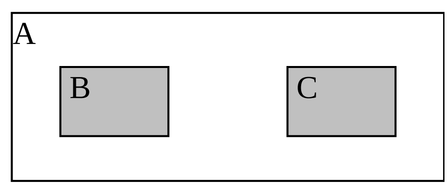

Figure 4 – Mask used for detecting eye blink in differential image.

It is expected that changes in gray regions are maximized and changes in white regions are minimized during eye blink. Thus, the sum of pixels in black boxes minus the sum of pixels in white boxes is a good parameter to detect eye blinks. These values can be easily obtained with no computation using integral image and this formula:

$$p_{blink} = \frac{2*(C_B + C_C) - C_A}{W_A * H_A} \qquad \text{(eq. 5)}$$

where C_x is the number of pixels in rectangle x (A, B, or C), and W_A, H_A are width and height of rectangle A respectively. When P_{blink} exceeds a predefined threshold (e. g. 0.1) a blink has occurred. Figure 5 shows the result of monitoring this feature and detection of blink.

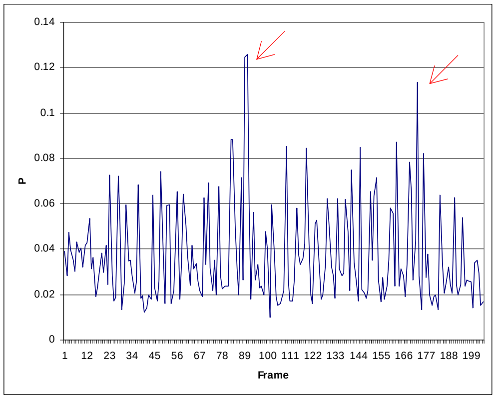

Figure 5 – chart of P_{blink} over time (about 200 frames). Two blink were detected (about frame 88, and 177).

Because the size of eyes and their position is not known, the mask is moved with big steps (10 pixels) from top left of the image to the bottom right, with different sizes(from 50 pixels to 120 pixels). After the best match is found, a fine tuning step is used to find the best position of the eyes by smaller steps. If the score of applied mask found at this position is above a predefined threshed (0.1), the blink has occurred. The process is summarized in figure 6.

Figure 6 – An example of blink detection. Blink is detected in last frame (right most images) and is highlighted in earlier frames.

4.1.4 Eye Tracking

After the position of eye is estimated using initial eye blink detection, four samples of open and close eyes are captured as templates for tracking from last frame and its successors. Usually, last frame from eye blink detection step contains closed eyes. By looking back in the frame histories, the frame with no change in the eye regions should contains open eyes. By tracking the eyes using open and close eye templates, whichever is better, the user's head and eye position can always be estimated and also the presence of user can be detected using this tracking. The presence of tracking is one of the algorithm's outputs that will help the prevention method to warn user in a long computer usage. The tracking is implemented using normalized correlation coefficient [21] as follows:

$$corr = \frac{\sum_{x,y}[f(x,y) - f_{u,v}][t(x-u, y-v) - tt]}{\sqrt{\sum_{x,y}[f(x,y) - f_{u,v}]^2 \sum_{x,y}[t(x-u, y-v) - tt]^2}} \quad \text{(eq. 6)}$$

where *f(x, y)* is the brightness of the video frame at the point *(x, y)*, $f_{u,v}$ is the average value of the video frame in the current search region, *t(x, y)* is the brightness of the template image at the point *(x, y)*, and *tt* is the average value of the template image.

Because open and close eye templates are not accurate, they cannot be used for detecting blinks. Temple matching on differential image is still used and tracking process provides a Region of Interest (ROI) for the template matching. If tracking system fails to track eyes, ROI will initialize to whole image region and everything starts from the beginning.

4.2 Proposed Prevention and Treatment methods

The software designed for the purpose of this research has three techniques to prevent exhaustion of the eyes. The simplest and short term method is to notify user to blink regularly. By using a predefined frequency for eye blinks, the system track user eyes if it could not detect user's eye blink after a period of time, a notification will be display to the user (Figure 7-a) to remind her of blinking. The system will remove the message immediately after it detects eye blink or user clicks on the message. Although this simple method keeps eye blinks' frequency high enough, it can be somehow annoying in a long period.

Another method to prevent dry eye is to track blink frequency and warn the user to take a short break when his eye blink frequency drops bellow a predefined value. This medium term technique is better that the previous one and it is also better than constant time breaks proposed by 20-20-20 rule, because break intervals depends on the user eye exhaustion computed by blink frequency. If user's eye blink frequency is low, it seems that she is tired and a short break is proposed by the software. Figure 7-b shows the notification of this technique.

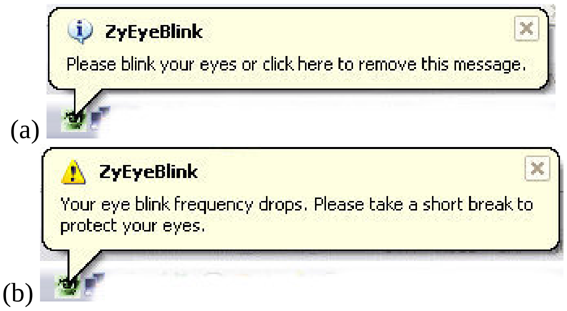

Figure 7 – two examples of messages that CVSS shows in system tray to communicate with user.

The long term solution of this system is logging. The system logs users' eye blinks, their duration and period in a file. This file can be reviewed and analyzed by the user or an oculist to propose long term solution to users that show more severe CVS symptoms.

5 Experimental Results

The System was tested with three users. At the beginning, all three users found the system annoying, because showing a message and playing a sound each four or five seconds is really uncomfortable, but in time, they got used to it. To prevent this message to appear, they tried to blink clearly with long duration. Figure 8 shows detected eye blinks for each of the three users. They work with the system for a while without complaining about eye strains.

Figure 8 – Three users tested the system. First raw show picture of users with open eye and second row are the pictures system shot when it detect eye blinks.

The system is also used in rest and silent modes and the results of these executions are summarized in table 1.

Table 1 - Summery of CVSS usages. Frequencies are in minutes^{-1} and intervals are in minutes.

	Active mode: initial blink frequency	Active mode: settled blink frequency	Rest mode: average proposed rest intervals	Silence mode: average blink frequency
User1	5	12	20	4.3
User2	7	14	18	5.4
User3	6	12	15	3.5

6 Conclusion

In this paper, a computer vision software solution (CVSS) is proposed to prevent computer vision syndrome (CVS). This CVSS incorporates a simple low resolution web cam that exists in most modern computers and laptops, to trace user eyes in real time, with no special hardware or accessory. The system counts eye blinks and logs their duration during a normal computer usage. This CVSS has three solutions to help users handle CVS. Short term solution measures blink intervals and warn the user to blink regularly thus preventing eye dryness. On the other hand, medium term solution proposes the user to take a rest on low blink frequency, and finally, the long term solution logs user's blinks to be analyzed by an oculist or by the user herself at a later time in silence mode. Experiments show that the system can detect and analyze blinks in real time with low true-negatives and very low false-positives and it succeeds in increasing user's blink rate through various notification methods. This paper's method also enables researchers to experiment in real situations with real users and there is no need to design special tasks to evaluate a CVS therapy.

For future works, the system can be implemented on a dual core architecture that is also available in today's notebook and computers. This can reduce time complexity of the system and result in a less CPU utilization, thus less interfering with main user applications.

References

[1] Yan, Z., Hu, L., Chen, H., Lu, F., Computer Vision Syndrome: A widely spreading but largely unknown epidemic among computer users, *journal of Computers in Human Behavior, Elsevier,* vol. 24, p. 2026-2042, 2007.

[2] Skilling, F. C., Weaver, T. A., Kato, K. P., Effects of two eye drop products on computer users with subiective ocular discomfort, *Journal of the American Optometric Association, Elsevier,* vol. 76, no. 1, p. 47-54, January 2005.

[3] Nelson, J. D., Helms, H., Fiscella, R., A New Look at Dry Eye Disease and Its Treatment, *Journal of Advances in Therapy, Springer,* vol. 17, no. 2, p. 84-93, March/April 2000.

[4] Blehm, C., Vishnu, S., Khattak, A., Mitra, S., Yee, R., Computer Vision Syndrome: A Review, Survey of Ophthalmology, Vol. 50, No. 3, May-June 2005.

[5] Tsubota, K., Tear Dynamics and Dry Eye, *Journal of Progress in Retinal and Eye Research, Springer,* vol. 17, no.4, p. 565-596, 1998.

[6] Mohammed, A. W., Koggalage, R., Control of Mouse Movements Using Human Facial Expressions, *proceedings of international conference on Information and Automation for Sustainability,* Melbourne, Dec. 2007.

[7] Morris, T., Blenkhorn, P., Farhan, F., Blink Detection for real-time eye tracking, *Journal of Network and Computer Applications, Elsevier,* vol. 25, p. 129-143, Feb. 2002.

[8] Morimoto, C. H., Mimica, M. R. M., Eye gaze tracking techniques for interactive applications, Computer Vision and Image Understanding, Elsevier, vol. 98, p. 4-24, 2005.

[9] Hong, T., Qin, H., Sun, Q., An Improved Real Time Eye State Identification System in Driver Drowsiness Detection, *proceedings of IEEE International Conference on Control and Automation*, China, May 2007.

[10] Miyakawa, T., Takano, H., Nakamura, K., Development of Non-contact Real-time Blink Detection System for Doze Alarm, *Proceedings of SICE Annual Conference in Sapporo, Japan,* August 4-6,2004

[11] Ohno, T., Mukawa, N., Kawato, S., Just Blink your Eyes: A Head-Free Gaze Tracking System, *proceedings of Conference on Human Factors in Computing Systems*, Florida, USA, 2003.

[12] American Optometric Association, The Effects of Computer Use on Eye Health and Vision. *St. Louis: American Optometric Association,* 1995.

[13] Anshel, J., Visual Ergonomic Handbook, CRC Press
Taylor & Francis Group, 2005.

[14] Yaginuma, Y., Yamada, H., Nagai. H., Study of the relationship between lacrimation and blink in VDT work, *journal of Ergonomics, informaworld.com,* vol. 33, no. 6, p. 799-809, 1990.

[15] Mori, A., et al., Quantitative videographic analysis of blink patterns of newscasters, *Graefes Arch Clin Exp Ophthalmol, Springer,* vol. 246, Page 1449-1453, 2008.

[16] Palakuru, JR, Wang, J, Aquavella, JV, , *Investigative Ophthalmology & Visual Science*, Vol. 48, No. 7, Page 3032-3037, July 2007.

[18] Chau, M., Betke, M., Real Time Eye Tracking and Blink Detection with USB Cameras, Boston University Computer Science Technical Report No. 2005-12.

[19] Gorodnichy, D. O., Second Order Change Detection and its application to Blink-Controlled Perceptual Interfaces, Proceedings of the International Association of Science and Technology for Development, Conference on Visualization, Imaging and Image Processing (VIIP 2003). pp. 140-145. Benalmadena, Spain, September 8-10, 2003.

[20] Viola, P., Jones, M. J., Robust Real-Time Face Detection, *International Journal of Computer Vision, Springer,* vol. 57, no. 2, p. 137–154, 2004.

[21] K. Grauman, M. Betke, J. Gips, and G. Bradski. Communication via eye blinks - detection and duration analysis in real time. *Proceedings of the IEEE Computer Vision and Pattern Recognition Conference (CVPR 2001),* Vol. 2, pages 1010–1017, Kauai, Hawaii, December 2001.