Digital Eye Strain Reduction Techniques: A Review

PREETHI J SEEGEHALLI

Department of Electronics and communication, PES University, Bangalore, India
preethi.ait@gmail.com

Abstract—— Digital eye strain or computer vision syndrome (CVS) is caused when we spend considerable amount of time in staring at digital screens of desktop computer, laptop, e-readers, tablets and mobile phones. This paper discusses the different the causes for visual fatigue and digital eye strain reduction techniques like usage of optical glass, flicker free screen, color filtering, fuzzy logic based brightness adaption technique, bias lighting screens, optimizing monitor's color temperature and Auto brightness control of digital screen. The paper also discusses the good practices to reduce visual fatigue.

Keywords- Digital eye strain, computer vision syndrome, eye strain reduction, colour filtering, visual fatigue, fuzzy logic

I. INTRODUCTION

With the usage of digital screens we are exposing ourselves to harmful wavelengths of light emitted by screens. Studies have shown that those who are using digital screens with the hours upon hours of close focusing without having a break for extended period of time are at the high risk of digital eye strain. Symptoms of Computer Vision Syndrome (digital eye strain) includes difficulty in focusing images, head ache, blurry vision when looking away from the screen, irritated teary, red, dry, itchy eyes and dizziness.

A. Visual fatigue caused by reflection and glare

Some of the traditional techniques used to reduce digital eye strain include using computer glasses which are made to help reduce the eye strain [1]. The computer glass has anti reflective coating and glass color tinting. Anti reflective coating is an optical coating applied to the surface of optical elements to reduce reflection and glare. If we have anti glare display it avoids the eye strain when the monitor faces a light source. We need not deal with the annoying reflection in the screen from the light source. Glass color tinting is the tint color that decides how much of visible light reaches our eyes and how well we see other colors and contrast. Some tint enhances colors and some increases the contrast. For example rose/red color tinting increases the contrast by blocking blue light. Many people feel that rose tinted lenses are more comfortable for long period of time, they reduce glare, eye strain and are soothing to eyes.

B. Visual fatigue caused by screen flicker when refreshing screen

In digital screens, the eye strain is caused due to screen flicker when there is a significant change in the brightness of light that reaches the eyes. Screen flicker occurs due to monitor's refresh rate (the speed with which the screen is redrawn) [2]. The digital screens have to be refreshed as they do not have the capacity to hold a stable image on the screen. They just give the illusion of a constant image, but in fact they are refreshing frequently. For example in CRT a single electron beam scans horizontal lines of pixels across the screen, lighting up each pixel when the beam hits it. The pixels are made up of phosphor dots that glow when the beam hits them. To our eyes the dots glow for about 1/30th of a second and fades away, to keep the display on, the screen has to redraw the display. The screen will glimmer if the refresh rate is too slow. If the monitor's are refreshed every 3sec they would be unstable. When the refresh rate is around 50 times a sec then the shifts are less noticeable and reduce visible flickers. However flicker is still present causing feelings of discomfort and eye strain. Higher refresh rate eliminates this problem. In today LCD monitors replace CRT, but LCD displays are still prone to screen flickering. LED screens that consume less power, now replaces cold cathode fluorescent lamp (CCFL), which are standard lamps used in LCD displays. Unlike LCD, LEDs do not have a "glow" period between the light turned on state and off state. As a result LEDs create more noticeable flicker than LCDs. LCD backlight has a more gradual light curve and LED backlight has a very sharp drop. This is because CCFL backlight emits between cycles but LED doesn't have this effect it creates a more drastic perceivable change between light on and off. It is the drastic change of light intensity that creates a flicker.

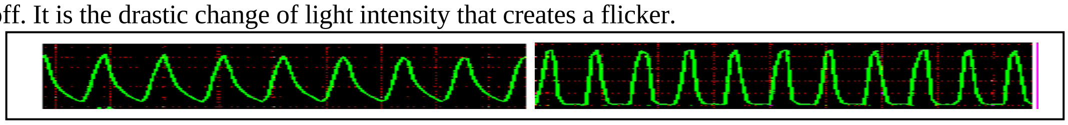

Figure 1: LCD and LED backlight curve

C. Visual fatigue caused by screen flicker due to PWM Brightness control

The digital displays brightness can be altered to match both dim and bright environments. Screen can be set to comfortable brightness level depending on ambient lighting. Changing the display brightness is achieved by decreasing the total light output for both CCFL and LED backlights. Traditional method used to dim backlight is pulse width modulation (PWM). But this PWM method is the source of visible flicker and eye fatigue. PWM decreases the brightness of display by cycling the backlight on and off very rapidly at a frequency that we can't detect naked eye. In this method 100% brightness means a constant voltage is applied to the backlight and it is continuously lit [3].

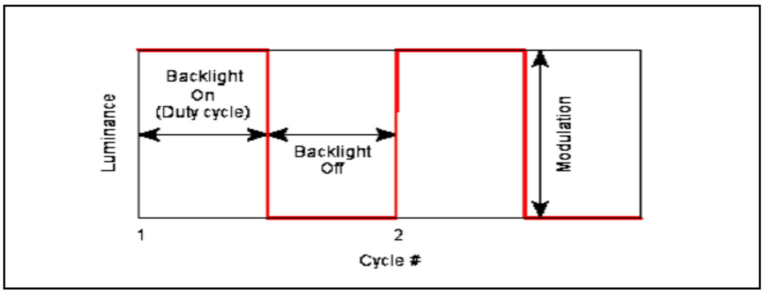

Figure 2: Pulse width modulation for brightness control

The backlight is cycled on and off very rapidly and this cycling occurs at fixed frequency. This frequency can impact whether the flicker is visible to the viewer. High frequencies are less problematic, but PWM operate at low frequencies of 180-240 Hz, generally low frequencies results in screen flicker. Modulation is the difference between "on" and "off" state. By altering the duty cycle the total brightness of backlight can be modified. As we decrease the duty cycle, the brightness gets lower and lower. This technique works visually as cycling backlight on and off is sufficiently fast so that the user will not be able to see the flickering.

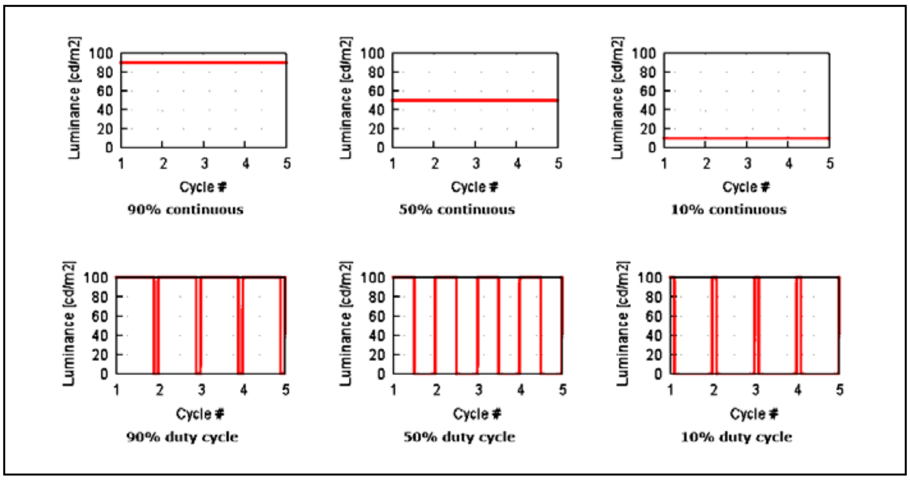

Figure 3: Perceived brightness for 90%,50% and 10% PWM cases

For the same duty cycle the flicker from LED backlights is more noticeable than for CCFL backlights because LED's can switch on and off much faster and do not continue to "glow" after the power is off. PWM can affect eyes when the user's eyes are moving quickly. New technology monitors that use DC backlight system in place of PWM eliminate the flicker caused by brightness control system.

D. Visual fatigue caused by Blue Light

Digital screens emit dangerous blue light, which is the highest energy wavelength of visible light. The effects of blue light are cumulative and lead to eye diseases like macular degeneration [4].

II. EYE STRAIN REDUCTION TECHNIQUES

A. Colour filtering.

Prolonged exposure to blue light is harmful. As we get older, our eye lens turns yellow. This is the natural way that our body protects us from the blue wavelength light. Visual fatigue caused when reading on LED and LCDs in white and sepia background was studied by Haruo Isono through subjective assessment and by critical flicker frequency (CFF). The results showed that when the background was changed from white to sepia, the eye strain reduces. This conveys that the high intensity blue light emitted add to visual fatigue. UV light is dangerous to our skin and also our eyes. UV light affects the front of the eye (cataract formation), where as blue light affects the back of the eye (risk of macular degeneration). Digital displays like LED lights and compact fluorescent lamps (CFLs) emit a high level of blue light. CFLs emit 25% of harmful blue light and LEDs emit 35% of harmful blue light. Blue light proportion will be higher if white LED is cooler [5].

Essilor splits the visible light into multiple bands of 10nm and then each band was focused on porcine retinal pigment epithelial (RPE) cells for several hours. In this method he identified that specific band of blue light 415nm to 455nm was most harmful to the retina and to the RPE cells. The blue-violet light 40nm band of visible light caused maximum retinal cell death. Our eyes are exposed to various sources like sun, LED, CFLs, which emit blue-violet light. The cumulative and constant exposure to the blue-violet light can cause retinal cells damage and slowly results in retinal cell death and can lead to AMD. All blue light is not bad, blue-turquoise light in the range 465 nm to 495nm is essential for our vision and to regulate our circadian sleep/wake cycle [4].

RGB color model is an additive color model, used by digital screens [6]. These match the biology of human eye which is made up of red, green and blue light sensors called as cones. In RGB additive color model red, green and blue light are mixed together in all possible ways to generate a huge array of colors. Digital displays work by having independently controllable red, green and blue elements. Visible blue light can be removed by attenuating blue plane intensity values. Above figure 7 shows the results after removing blue light from the original image. When the blue color is removed image appears to be yellow. By color filtering, we will be unable to reproduce the range (gamut) of colors that can be reproduced by combination of RGB. The yellow Amber lens absorbs blue and ultraviolet light and is found to have reduced eye strain.

B. Fuzzy logic based brightness adaption technique.

A screen that is too bright or too dark is too difficult to see and adds to eye strain. The screen brightness should be adjusted to an appropriate level in response to ambient lightning. One of the main reasons for eye strain is the relative illumination between the screen and its environment. This can be overcome by adjusting the brightness of the screen with respect to the environment light. People surfing through screens get affected due to huge contrast between outside atmospheric light and screen brightness. Additional stress occurs when there is contrast difference. Manual adjustment of brightness requires that there is continuous adjustment of brightness depending on surrounding light. Therefore automatic adjustment of contrast and brightness is preferred [7].

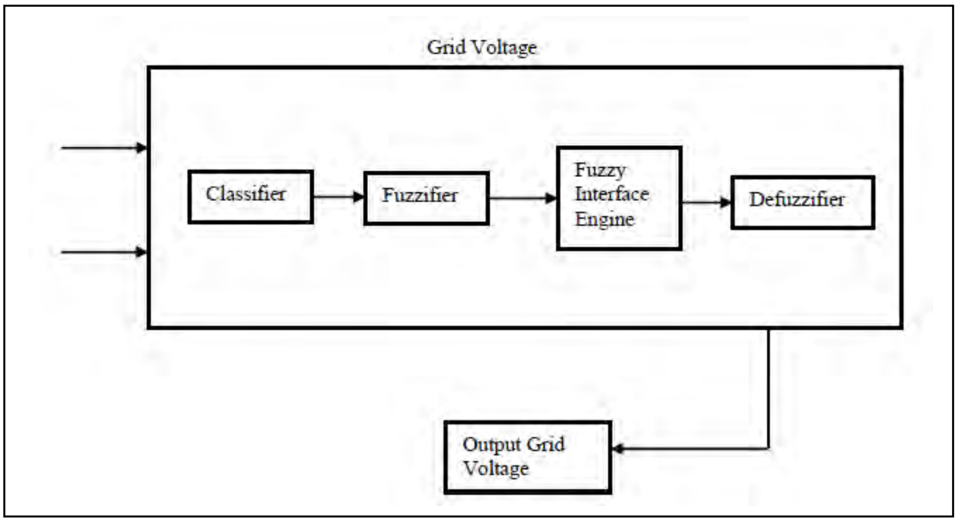

Figure 4: Fuzzy logic based brightness adaptation

The fuzzy controller takes the intensity of atmospheric light (measured using photo sensor) and the current screen brightness as the input, and the output is the required brightness of the screen to match the ambient lightning. The atmospheric light and screen brightness is divided into five categories.

Triangular membership function of intensity of Atmospheric light

1. Very Dark: -4 to 3 mv
2. Dark: 3 to 8 mv
3. Medium: 8 to 17 mv
4. Bright: 17 to 25 mv
5. Very bright: 25 to 45mv

Triangular membership function of required brightness of screen

1. Very low screen brightness: grid voltage 150v to 160v
2. Low screen brightness: 160v to 170v
3. Medium screen brightness: 170v to 180v
4. High screen brightness: 180 to 190v
5. Very high screen brightness: 190v to 200v

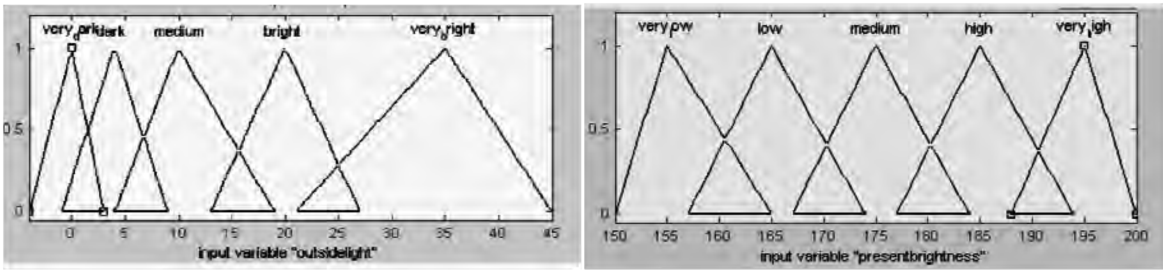

Figure 5: Membership function of atmospheric light and screen brightness

The membership function employed here are triangular membership function. The range of voltage of each membership function is chosen such that its screen brightness equivalent matches closely with the ambient surrounding light. The fuzzifier classifies inputs to one of the membership types. Classified inputs are compared with rule base and the required voltage corresponding to screen brightness appears at the output of the fuzzy controller. Thus the difference in screen brightness and ambient surrounding light is continuously monitored and adapted using fuzzy logic. The defuzzification technique used here is centroidal defuzzification.

Rule1. IF atmospheric light is “very dark” Then screen brightness is “very low”
Rule2. IF atmospheric light is “dark” Then screen brightness is “low”
Rule3. IF atmospheric light is “medium” Then screen brightness is “medium”
Rule4. IF atmospheric light is “bright” Then screen brightness is “high”
Rule5. IF atmospheric light is “very bright” Then screen brightness is “very high”

C. Bias lightning screens.

Human eyes work on basis of system of averages. When we look at something like digital screen, vehicle head lights in the distance or good scenery, pupils dilate to regulate how much light pass through our eyes. The degree of dilation is triggered by the entire scene that our eye takes and not by the single brightest point of light within the scene. When we watch screen during night in a dark room, our eyes will be staring a small screen of bright light very intently. Our eyes tries to adjust dilation based on average brightness of the entire scene. Our eye does not adjust dilation on average brightness of the screen. As a result there is eyestrain.

We can increase the general brightness in the room in order to avoid eye strain caused by watching digital screens in a dark room. All ceiling lights, table lamps or floor lamps will be placed either above or in front of screen. These lights, introduces glare and mist to the image on the screen and adds to eyestrain. To overcome this bias light is placed behind the screen we are viewing, such that it increases the ambient light levels in the viewing area. Bias light originates outside the sightline of the viewer and thus avoids shining light toward the viewer [8].

Color temperature is the important factor to consider while choosing bias light for screens. Light bulbs have a color temperature measured using Kelvin color temperature scale. If color temperature is lower it will be more red light and warmer. If color temperature is higher it will be more blue light and cooler. Candle flames are 1900k and cast reddish/yellow light and are warm. Standard incandescent light are 2800k and quite warm. Day light bulbs have color temperature 5000-6500k and are cool white. To select right bulb we want the bulb color temperature to match with the color temperature of digital screens (i.e. 6500k).

D. Optimizing monitor’s colour temperature.

Color temperature affects the picture quality and color reproduction. If color temperature is lower, the white object appears redder, if color temperature is higher; the white object appears blue [9]. Open up a blank white screen and adjust the color temperature of display to match the color temperature of lightning environments. This will help to reduce visual fatigue.

Color temperature (sunlight)		**Color temperature (Artificial light)**	
Clear sky	12000k	Day light (florescent)	6500k
Shade on clear day	8000k	Day white (florescent)	5000k
Cloudy sky	6500k	White (florescent)	4200k
Average noon sunlight	5300k	Warm White (florescent)	3500k
Two hours after sunrise	4500k	Soft White (florescent)	3000k

Table 1: color temperature of lights.

E. Auto brightness control of digital screen.

The display screens are maintained at close distance of approximately 20 inches (50 cm) from the viewer's eyes. In order to focus the screen the eye muscles are in constant tension which results in stress and fatigue of eye muscles. Because eye muscles are often held in the same state for an extended period of time, eye muscles are not allowed to adjust, refocus and relax. This problem is general with digital screens that have constant intensity or brightness. The viewer stares at screen form a constant distance and same brightness for long time, accordingly eye muscles don't get opportunity to relax or adapt. It is observed that when reading a book eye strain is less compared with reading a book on digital screen. This is because reader has to refocus eyes for the next page and the turning of book page temporarily changes the brightness of the page. The eye muscles adapt to this change and eye fatigue is less. Whereas digital display has no change in brightness and user often do not look around the room or other objects of different brightness or frequently blink their eyes. Therefore to avoid eye strain and fatigue there is a need for the viewer to occasionally adjust or refocus their eyes. It is believed that reduction in eye strain and fatigue occurs if the muscles of the eyes are regularly moved and adjusted. For example, a person can hold their arm in a constant outstretched position for a limited period of time. And because of constant outstretched position the arms are strained. But a person, who is regularly moving their arm like an orchestra conductor, can hold their arm outstretched for a much longer duration. Their arms are stressed less. Thus the regular adjusting and exercising of the eye muscles will allow the person to view a digital display for a much longer period of time than otherwise would be possible. The moving and adjusting of the muscles in the persons eyes should occur regularly to prevent the muscles of the eyes from being held in a constant state of tension. At the same time, very active movement of the muscles of the eye should also be avoided to prevent fatigue. Accordingly the brightness of the display is preferable adjusted such that the muscles of the eye are regularly exercised, but not to the extent that the eye muscles are fatigued [10].

Instead of constant brightness the brightness of the digital screen is adjusted according to specific pattern like sine, triangle, trapezoidal and random. Time period is the length of brightness adjustment cycle. The brightness varies with in a range centered about the general brightness level. Always the range of brightness need not be centered about general level of brightness, alternatively general level of brightness can be maximum brightness and the brightness will vary within a range that will not exceed maximum brightness or general level of brightness may be the minimum brightness and brightness will vary within a range that will not go below minimum level. The range of adjustable brightness is the extent the brightness varies. The range is expressed in terms of percentage of the selected general level of brightness of the display. For example range is 10% of general level of brightness. If general level of brightness is 50% of total brightness, then range of adjustable brightness is 5% (i.e. 10% of 50%) of total brightness. In this example the brightness will vary within the range of about 47.5% and 52.5% of the total brightness of the display. The range of brightness can be randomly varied if random pattern is selected. If generated random number is in between 1 to 256, then range is selected as follows.

If random number generated is between 1-100 then range of brightness =5%
If random number generated is between 101-200 then range of brightness=10%
If random number generated is between 201-256 then range of brightness=15%

Prior to the end of the period a new random number is generated to select a new range of brightness for the subsequent period. This allows the system to continuously vary the brightness in the desired manner until the user stops the system. The time period of brightness adjustment cycle is set to five minutes. The brightness of the display may be adjusted at intervals of less than five minutes such that the eyes of the viewer must more frequently adjust to the brightness of the display or the brightness of the display may also be adjusted at intervals of every second or even less such that brightness is almost gradually changing. The time period of the cycle may be chosen with the help of random number generation in a manner similar to selection of the brightness adjustment range. If the brightness changes are gradual and imperceptible to the user, then the user is adjusting the muscles in their eyes without being aware of the changing brightness of the display.

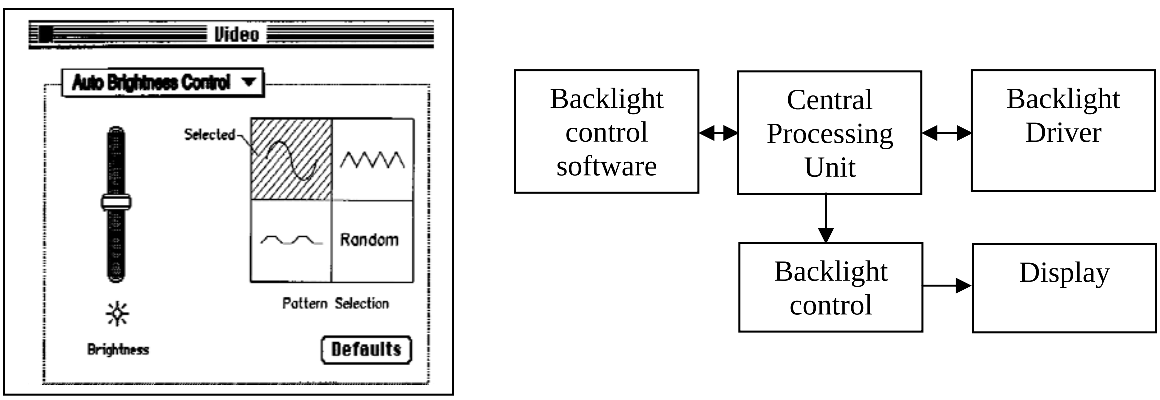

Figure 6: Auto brightness control of digital screen.

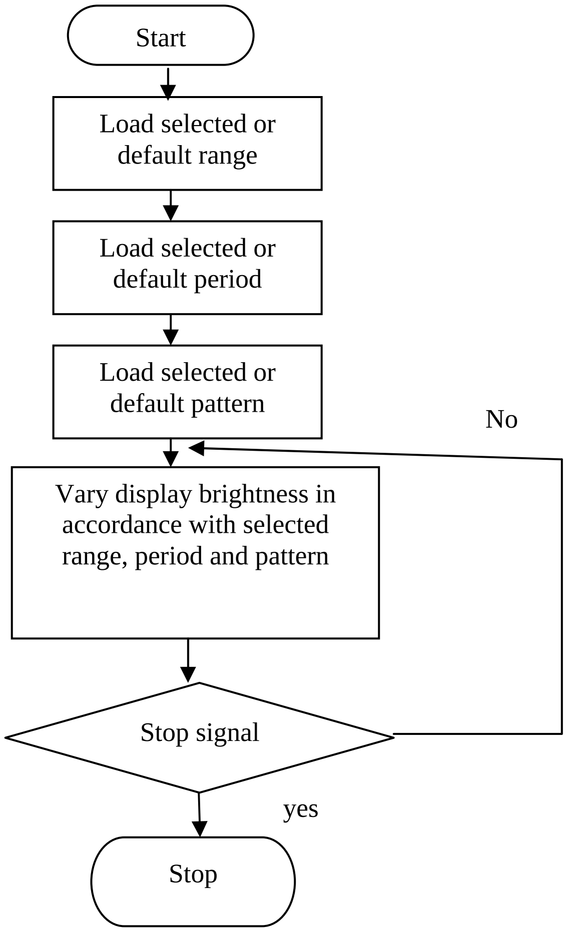

Figure 7: Flow chart of Auto brightness control of digital screen.

III. GOOD PRACTICES TO REDUCE VISUAL FATIGUE

Blinking eyes prevents dryness and irritation. People often blink less frequently when they are working on screens. During non blinking phase the tears coating eye evaporate and this leads to dry eyes [11]. Focusing the screen for a long time also results in eye fatigue, to overcome this look over a distant object away from the screen at least every 20 seconds. Looking far away reduces eye fatigue by relaxing focusing muscle inside the eye. Taking frequent mini breaks helps to reduce eye fatigue. The viewing distance between eyes and screen should be in the range of 40 to 74 cm. Place the screen to minimize the glaze from lights and windows. Blur images and bad quality images with less contrast add to eye fatigue [12]. So always it is preferred to watch good quality image on the screen. Small fonts and bright background also results in visual fatigue so choose the combinations of text color and background color with care [13]. Choosing black background is good, because for black display no light is emitted from screens, no light means that there is no eye strain. If white background is selected then for white display light is emitted from screens, which falls on eyes to cause eye strain.

The contrast, when using a dark background with strong light letter forms, the iris opens to allow more light in, and that causes letter forms to blur. For people with astigmatism (approximately 50% of the population) find it harder to read white text on black than black text on white. Because with a bright display (white background) the iris closes a bit more, decreasing the effect of the "deformed" lens; with a dark display (black background) the iris opens to receive more light and the deformation of the lens creates a much fuzzier focus at the eye.

IV. CONCLUSIONS

In today’s digital world, we use digital screens to perform tasks which require particular visual attention and most of them dislike reading from digital screens or working on digital screens because of visual fatigue. The paper covers a detailed review of all digital eye strain reduction techniques and practices used. But still we are not able to come out of visual fatigue without affecting the quality of digital image being viewed. Further research in this direction is necessary to beat computer vision syndrome (CVS).

V. REFERENCES

[1] Croft, Joseph (San Clemente, CA, US), Michelsen, Matthew (San Diego, CA, US), Joyce, Robert (San Marcos, CA, US), U.S. Patent 20150153591, 2015, “LOW-POWER EYEWEAR FOR REDUCING SYMPTOMS OF COMPUTER VISION SYNDROME”

[2] Blehm, Clayton, et al. "Computer vision syndrome: a review." Survey of ophthalmology 50.3 (2005): 253-262.

[3] Yong, Sea-Weng, Chih-Chiang Huang, and Yi-Hsien Lee. "Method and related device for controlling illumination of a backlight of a liquid crystal display." U.S. Patent Application 10/064,459.

[4] Kirk Smick, O. D., and Thierry Villette. "Blue light hazard."

[5] Haruo Isono, Apurva Kumar*,Takuya Kamimura,Yuuta Noguchi, Hiroyuki YaguchiClayton Blehm, (2013) “The Effect of Blue Light on Visual Fatigue When Reading on LED-backlit Tablet LCDs”, ABC Proc. of the 20th International Display Workshops (IDW’13), VHFp-9L

[6] Gonzalez, Rafael C. Digital image processing. Pearson Education India, 2009.

[7] Balasubramanian, AV Sai, et al. "A Novel Fuzzy Logic Based Controller to Adjust the Brightness of the Television Screen with Respect to Surrounding Light." World Academy of Science, Engineering and Technology 39 (2008): 188-191.

[8] Bindemann, Markus. "Scene and screen center bias early eye movements in scene viewing." Vision research 50.23 (2010): 2577-2587.

[9] Huang, Rong-Hwa, et al. "Effects of Color Temperature of LED Desk Lights on Working Attention." 2013 International Conference on Business and Information (BAI 2013), Bali, Indonesia. 2013.

[10] Wagner, Roger. "Anti-eye strain apparatus and method." U.S. Patent Application 09/963,250.

[11] Stern, John A., Donna Boyer, and David Schroeder. "Blink rate: a possible measure of fatigue." Human Factors: The Journal of the Human Factors and Ergonomics Society 36.2 (1994): 285-297.

[12] O’Hare, L., and P. B. Hibbard. "Visual discomfort and blur." i-Perception 2.3 (2011): 191-191.

[13] Hall, Richard H., and Patrick Hanna. "The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention." Behaviour & information technology 23.3 (2004): 183-195.

AUTHORS PROFILE

Preethi S.J. received the B.E in electronics and telecommunication in the year 2005 and M.Tech in computer science and engineering in the year 2008 from Visveswariah Technological University. She is now working as Assistant professor in PES University, Bangalore, India.