White Paper

Effect of Improved Display Quality on Eye Health

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Abstract

Asthenopia, or eyestrain is a common complaint associated with digital media consumption and is especially prevalent among users of hand-held devices. In this paper, we examine existing methods for mitigating and alleviating eyestrain as well as objective and subjective measures of the condition. Our dual goals are to determine the effect current IRYStec processing methods (DRIVEvue, MOBILEvue, and MYvue) have on eyestrain and to find new ways to reduce discomfort in modern displays. Our review of causes of eyestrain suggests that the image processing by IRYStec software reduces eyestrain by increasing the perceived contrast of displayed imagery.

Background

In most developed countries, individuals spend an average of 8.5 hours a day in front of electronic displays, doing their work, participating in social media, playing games, and viewing entertainment. Studies have shown that eyestrain sets in after 3.5 to 4 hours of continuous exposure [1,2]. This may lead to further discomfort in the form of headaches and muscle strain [3]. Aggravating factors include inadequately corrected vision, high (or low) ambient lighting, small typefaces, inferior display quality, and poor choices of background or foreground colors that reduce contrast or induce afterimages.

Despite the widespread nature of asthenopia, the problem gets little attention except from optometrists, who may be called to assist display users with specialized eyeglass prescriptions. However, for every individual who wears tailored "computer glasses" for their work, there are a dozen who get by with uncorrected vision or a general correction or are so young that they have never had their vision tested. Worse, a child's eyes can deform to myopic (oblong) shape as a direct result of prolonged viewing, requiring correction and increasing the risk of a retinal detachment and related issues later in life [4-5].

While we understand some of the causes and factors related to eyestrain, we have barely begun to explore ways to improve the viewer experience. Increasing contrast is one obvious approach, as is balancing display luminance to the surroundings, reducing or controlling certain parts of the spectrum, changing refresh rates, reducing reflections, and so on. Some of these methods are included in IRYStec's current process, and others have yet to be tested. We will look at some of what has been done by ourselves and others and consider new approaches to the problem and how they might be evaluated. We will start with a review of eyestrain and how it is characterized in the next section. We then look at current IRYStec processing and its effects on asthenopia. We conclude with a general statement on future prospects.

Measurement of Eyestrain

Eye-strain can be measured through objective and subjective methods. While objective methods typically attempt to correlate ocular characteristics and behavior of the eye with eyestrain, subjective approaches rely on evaluating individual experiences related to eye fatigue. Generally speaking, asthenopia can be induced through a multitude of causes, such as for example reduction of contrast or presence of afterimages. It is thus, relevant to study eyestrain under a wide variety of conditions and describe the associated ocular response.

Among the most common objective measurements are the blinking rate [1-3, 6] and Electromyography (EMG) [3,6]. Blinking rate is shown to be an indicator of eye fatigue: it is observed to significantly decrease under eye-straining conditions. EMG, on the other hand, is a measure of the electrical activity of muscle tissue, namely the levels of nerve-to-muscle signal transmission. More specifically for estimation of eyestrain, EMG can be used to describe the orbicularis oculi response, which is increased under eye exertion or because of reduced contrast.

The two existing studies on eyestrain follow a similar approach. A group of subjects (20 and 31 individuals, respectively) is presented with a text reading task under two or more different conditions characterized by level of eyestrain. During the task and for each condition, a given measure of eyestrain is taken – the blinking rate and/or EMG. At the end of the task, subjects are also asked to complete questionnaires about visual discomfort experienced during the task. Overall, the studies are designed to investigate multiple factors influencing eye fatigue. Among the most common are the medium on which text is displayed, the size of the font, glare or low-contrast, and brightness of the display.

Eyestrain Studies with Low Contrast

In what follows, we will focus on reviewing the effect of contrast on eyestrain. Note that in the reviewed studies, contrast is defined as the contrast ratio between the luminance of text and the underlying background. The contrast can be calculated using the formula, (L_{max}-L_{min})/(L_{max}+L_{min}), where L_{max} and L_{min} correspond to maximum and minimum luminance values, respectively.

The study of Gowrisankaran et. al. investigated seven different asthenopia-inducing conditions, one which is low contrast. For each condition, the subjects were presented with a reading task of text on paper. For the non-stress condition, text was printed on white paper medium in Verdana font with font size of 10 points and was shown 60 cm away from the viewers' eyes. For the low-contrast condition, the text was printed using a gray color, thus reducing the contrast between the letters and the white background, making it barely legible. The contrast was calculated to be 3.5% from luminance measures obtained for the text and the background using a Pritchard photometer. For all conditions, the middle portion of the page was situated about 10 degrees below the straight-ahead gaze.

In their results, Gowrisankaran et. al. measured EMG readings that were significantly higher ($p=0.007$) for low-contrast condition (mean ratio of EMG power = 1.02) than for the non-stress condition (mean ratio of EMG power = 1.68). Furthermore, blinking rates for low-contrast were decreased ($p=0.041$) when compared to the non-stress condition. Regarding the associated symptoms, subjects reported that the low-contrast condition resulted in greater discomfort (mean discomfort score for low-contrast is 63.65 which is the second-highest score from the seven tested eyestrain inducing conditions, while the mean score of non-stress condition is 10.9). What is more, subjects felt that they spent more time reading the text under low-contrast condition rather than actual time spent, which implies larger accumulation of eye stress over time.

Nahar et. al. completed a similar study, but the medium on which text was shown was a display rather than paper. Once again, the study explored several lower-level visual stresses inducing factors, including low contrast levels. For contrast conditions, four different levels were used, namely contrast of 5%, 10%, 20%, and 40% (non-stress condition was not included). The results showed that there was no significant difference in EMG power for the four tested contrast levels (5~40%), however, blinking rate decreased with poorer legibility (as contrast decreased from 40% to 5%). For subjective discomfort ratings, subjects reported a decrease in comfort level with decreased level of contrast.

Overall, both studies show that low contrast conditions increase human eye's discomfort, which was observed to be correlated with a decrease of blinking rates and an increase of EMG readings. The contrast conditions that were expected to be more eyestrain inducing were thus shown to be associated with higher eye fatigue

Low Contrast in Real Life

Nowadays, there is no escaping exposure to electronic displays, which range from mobile phones to large TV panels. Many developed countries boast staggering statistics: an average of 8.5 hours a day in front of electronic displays, which for most individuals amounts to about half of the time spent awake. With such large demand and usage of displays, the display industry has known multiple technological advancements. Unlike older and less performant low dynamic range displays, modern panels are typically characterized by a high maximum luminance level of up to 500cd/m^2 (even higher for HDR displays) and a black level close to zero for LCDs, and zero for AMOLED displays, making for high or nearly infinite contrast ratios.

However, if ambient conditions and human perception are considered, the actual human eye perceived contrast is largely different. In fact, ambient conditions play a big role in how displayed content is perceived by the human visual system (HVS) [7-8]. Multiple factors come into play to affect the perception of colors, contrast, and thus the displayed content.

Consider viewing a mobile phone display under bright ambient light conditions, such as under direct sunlight outside in a park. The displayed content will be difficult to view and understand; it will appear washed out due to reflection of sunlight and the illuminated environment, glare from bright ambient illumination, etc. The display's apparent black level and maximum luminance are affected by these ambient conditions, although the physical contrast ratio of the screen is the same. The contrast ratio perceived by the human eye is thus decreased, leading to degraded image quality.

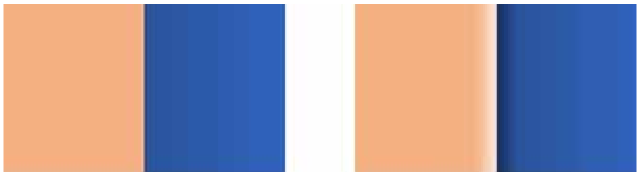
What about dark environments? While there is nearly no ambient reflection unlike in bright ambient conditions, viewing a bright display in dim conditions results in severe discomfort for human eyes. To avoid glare and dazzling effects, the screen can be dimmed in dark environments by auto-brightness functionality such as that present in nearly all mobile devices. This kind of dimming results in the maximum luminance of the display being reduced, while the minimum luminance remains unchanged, directly causing lower contrast. On top of this effect, the perceived contrast ratio is further decreased given the human eye's lower contrast sensitivity under dark luminance [8].

As such, for both bright and dark viewing conditions, perceive contrast ratio is decreased. As was previously discussed, lower contrast is correlated with higher levels of eyestrain. It is thus desirable to reduce the effect of ambient viewing conditions on perceived contrast.

IRYStec Processing and Contrast Enhancement

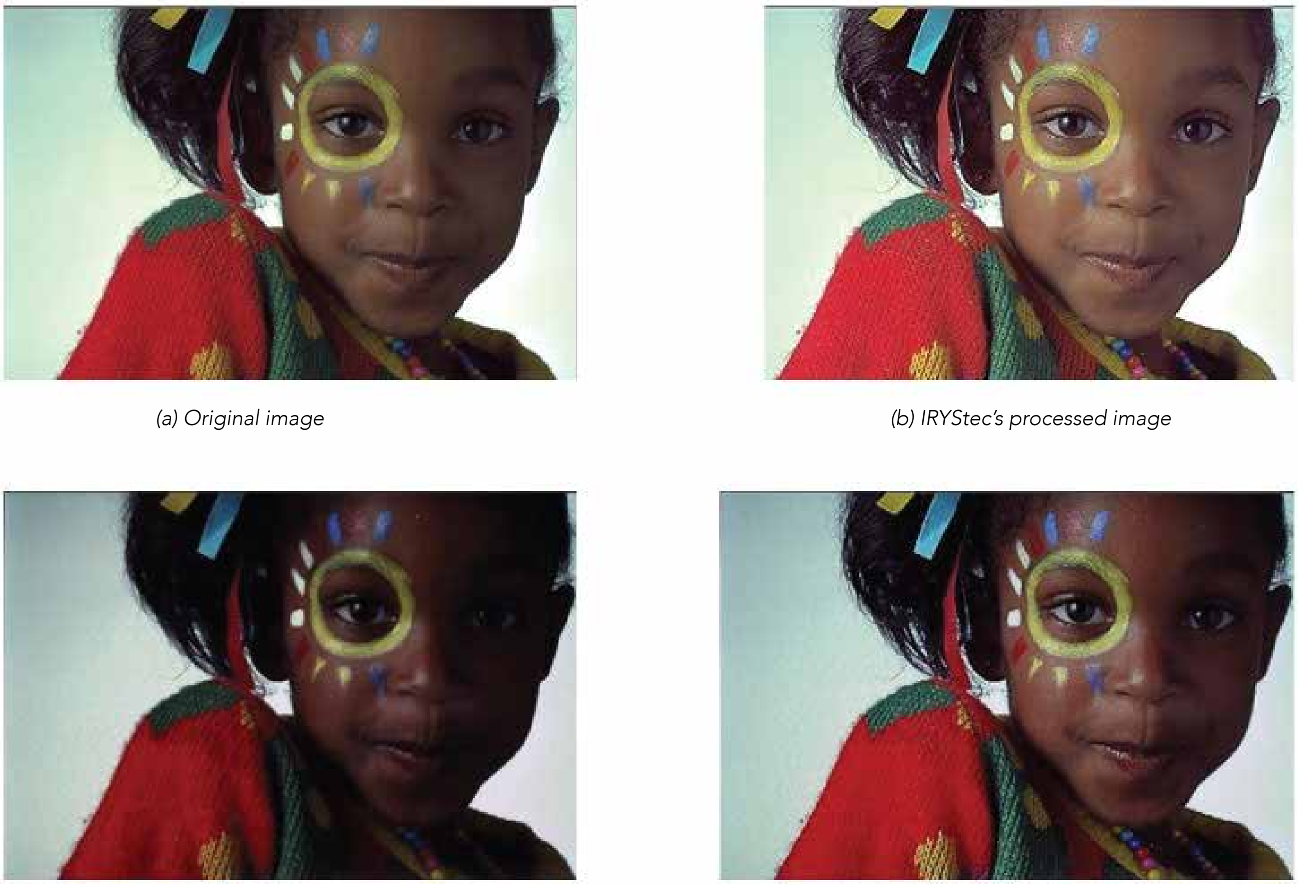
Since it is impossible to enhance the physical contrast of the display, IRYStec's processing adjusts contrast of the displayed content instead. This is intended to increase the perceived contrast ratio in both bright and dark environments while minimizing distortion from the original displayed content.

Figure 1 an example, how IRYStec software add contrast of contents.



(a) Original content *(b) IRYStec result*

Figure 1 shows a simple example of how IRYStec's image processing enhances contrast locally. In (a) the original content is shown: simple border between two regions of different color; (b) shows the original image with IRYStec's enhancement of contrast. Notice how the near-boundary pixels are modified: the bright are brighter, whereas the darks are darker; overall, the processed image has more contrast near boundary.



(a) Original image

(b) IRYStec's processed image

(c) Display the original image on Nexus5x under 5000lux

(d) Display the IRYStec's processed image on Nexus5x under 5000lux

Figure 2 Original image and IRYStec's processed image, and their perceived image by camera under bright environment.

Figure 2 shows IRYStec processing on more complex imagery under bright environment. (a) shows the original image and (b) is the processed image which has more contrast near boundaries. (a) and (b) are digital images, whereas (c) and (d) are the same images displayed on a Nexus5X mobile phone and captured by a camera under a bright environment (5000 lux illumination). Original image is perceived as being very dark and blurry under this bright environment as shown in (c), and the processed image is perceived (d) to be more similar in contrast and color as the original content shown in (a).

Effects of IRYStec Processing

One way to evaluate the effect of IRYStec processing is through use of image quality assessment (IQA) methods. As previously discussed, ambient illumination can be a source of image quality degradation and cause content to appear to have different image quality. For example, bright ambient light distorts the perception of imagery by causing glare and contrast reduction.

In our previous work, we used several prominent IQA methods to quantify image quality difference between processed and unprocessed images [11]. We used a digital camera to model a theoretical eye; appearance of unprocessed and processed images as viewed on a physical display panel under dark and bright ambient lighting conditions was then captured and compared. Our results show that all tested metrics (MSE, PSNR, and SSIM) are largely more favorable towards processed content (by up to 30%), which implies that the processed images have meaningfully higher quality when compared to the unprocessed content.

One of the objectives of IRYStec's processing is to counter the effect of contrast reduction induced through a variety of non-standard viewing conditions, e.g. high ambient lighting. Since IRYStec increases the perceived contrast for bright and dark environments and given the previously discussed relationship between contrast and eyestrain, we infer that IRYStec software effectively reduces eyestrain.

The relevance of such processing is strongly motivated by increased usage of display panels under a variety of non-standard viewing conditions. Handheld devices are typically used on-the-go, in any kind of viewing environments, which often results in reduced contrast of displayed content. Furthermore, modern automotive industry is more and more characterized by presence of a great number of digital display panels in cars, with larger and larger screen sizes, serving the purpose of not only the dashboard, but also entertainment. The aforementioned devices are thus prone to be used in diverse lighting conditions, ranging from very dark (in a tunnel, driving at night time, a dark room before sleep) to very bright (outside in a sunny day) ambient. Viewing displayed content in these extreme lighting environments is naturally associated with reduction of perceived contrast. Through studies, low contrast was revealed as one of the key factors causing eyestrain. Thus, minimizing contrast reduction is a solution to reducing eyestrain and is one of the benefits that IRYStec processing offers to consumers.

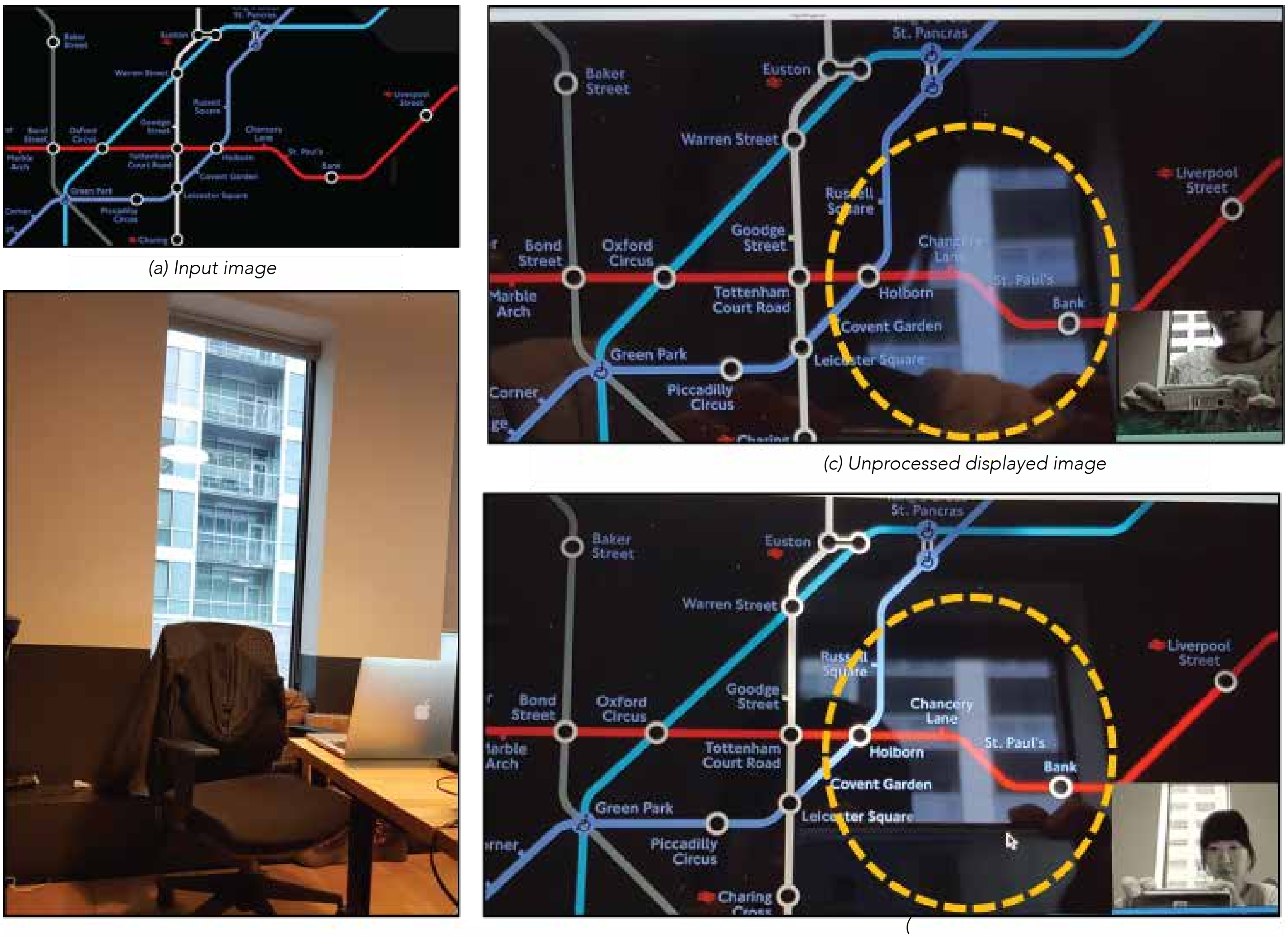
Avenues for Improvement and Future Work

In this paper, we discussed how IRYStec's processing can be used to help with eyestrain. In what follows, we would like to elaborate on ways of improving our current approach.

While contrast enhancement targeted towards compensating for average ambient illumination level is an effective means of mitigating image quality degradation associated with perception of physically displayed content, a more specific approach is to compensate image contrast in areas where quality degradations are most prevalent, namely in areas of reflection highlights. This is most noticeable when a display is illuminated by non-uniform lighting coming from the surrounding environment, as opposed to uniform point light sources such as unobstructed sunlight. This type of processing can be applied in many situations involving similar ambient conditions: computer displays in an office with windows, dashboard screens inside vehicles, etc.

Reflection mitigation typically involves viewpoint tracking, i.e. the position of the viewer with respect to the screen, with the goal of estimating how the surrounding environment is reflected from the screen and seen by the viewer. Presence of reflections implies loss of contrast; however, reflections may be non-uniform and thus have a positional component, which results in varying intensity of contrast reduction across the viewed surface.

In IRYStec's contrast enhancement processing, the average ambient illumination level is approximated by readings from a light sensor. This physical quantity is used to estimate the amount of degradations due to multiple factors, including reflection of the surrounding environment. An improvement to this process is to consider reflections with a positional component and apply stronger contrast compensation in areas where reflections appear to the viewer. Alternatively, the two compensation methods can be applied separately and in series, e.g. contrast enhancement followed by reflection mitigation.



(a) Input image

(b) Environment (window)

(c) Unprocessed displayed image

(d) Processed displayed image

Figure 3 Reflection mitigation processing of the highlight area: (a)input image, (b) test environment with a laptop (display), a camera on top of the display and a window in the background, as source of reflection, (c) physically captured screen of the laptop displaying the input image and showing reflection of the window (yellow dotted circle), (d) identical setup as (c), displaying the processed image, compensating the reflection area only; in (c) and (d), the front camera's captured image is shown on bottom left.

In our previous work, we explored the application of reflection reduction by positional contrast enhancement in everyday conditions, namely for computer and mobile displays [12]. In our experiments, we used a laptop display and the front mounted camera of the display to track the viewer's eye position and capture the environment. Figure 3 illustrates a situation in which reflected illumination from the environment reduces the contrast of displayed content: given original content (a) and the environment (b), we show the resulting unprocessed displayed content (c) and the processed version including our reflection mitigation (d). Note the improved contrast resulting in higher readability of the content. Our results offer strong motivation for further effort spent on optimizing and quantifying the associated improvement given by this method, namely its effect on image quality and viewer's comfort. We can hypothesize that since reflection reduction further minimizes contrast loss, eye fatigue would likewise be reduced.

Conclusion

The surge in usage of handheld display devices (smart phones, tablets, etc.) for all areas of our lives has drastically increased average exposure to display technologies. As the time one spends in front of various displays is ever growing, studies have observed increased eyestrain due to low contrast of displayed content. Objective (blinking rate, EMG) and subjective (discomfort rating) measures of eye strain were shown to be correlated under low-contrast conditions. We therefore deduce that increasing the contrast of displayed content can be a solution to reducing eyestrain. IRYStec software enhances image contrast, with the objective of ultimately presenting similar perceived contrast as is intended for the original contents under standard lighting condition. As the negative effect of intrusive viewing conditions on perceived contrast is mitigated, IRYStec also helps with reducing eyestrain.

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