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# Evaluating the Naturalness and Legibility of Whiteboard Image Enhancements

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## Abstract

*Over the years, there have been many studies conducted for whiteboard image detection, extraction and quality enhancements. However, the image quality attributes of the streaming whiteboard contents as well as users' expectations from such whiteboard scenes are not well investigated. Therefore, the primary goal of this work is to examine the effects of the different whiteboard image features on the overall quality of the whiteboard images. Particularly, the naturalness and legibility quality attributes of the images were investigated through psychovisual experiments. Our experimental results show that increasing color attributes such as saturation, brightness and luminance contrast, lead to more legible whiteboard contents; which in turn increases the whiteboard image quality. Enhancement processes of the whiteboard backgrounds, however, show strong effects on the naturalness attribute. But, when the general image quality is considered, observers tend to prefer more legible whiteboard image contents rather than the naturalness of the appearance.*

## Introduction

Whiteboards have been utilized as a flexible communication, instruction and planning mediums for different educational institutions, offices, hospitals, homes, and many more. With the increasing advancements of internet speed and bandwidth, many of the educational, business and personal communications began to take place online, via e-learning or videoconferencing systems. In most of the situations, the visibility of all of the illustrations made on the whiteboards are of utmost importance.

However, the streaming process of most of the above-mentioned communications are not usually professionally controlled. The camera quality, the camera position, the room illumination, and other related factors, for a better quality of the video streaming results, are not cautiously planned. Such types of unprofessional setups usually lead to quality degradation. Additionally, most of the current whiteboards are manufactured with highly reflective materials such as lamination, fiberboard coating with melamine, or hard-coating with ceramics. The reflective nature of such materials together with occlusion and nonuniform illumination, during the acquisition process, generates specular highlights and shadows; which, in turn, results in over- and under-exposures problems. Exposure problems in the video highly reduce the brightness and contrast of the whiteboard image and further hinders the visibility of pen stroke contents [1].

Accordingly, over the years, researchers have been proposing solutions for the enhancements of streaming whiteboard scenes. Most of the solutions, however, were intended to detect, extract and store the pen stroke contents of whiteboard regions [2, 3, 4, 5]. Some of them increase overall image contrast, remove specular light reflections and whiteboard region occluding objects. Few other solutions, on the other hand, consider the detection and color enhancement of whiteboard image regions [6, 7, 8, 9, 1]. Such methods, in addition to contrast enhancement, also perform color enhancement for pen stroke contents. All in all, the primary goal of most of the prior whiteboard image enhancement methods was to improve the quality of whiteboard image regions and increase the legibility of their contents.

The meaning of image quality as well as legibility for whiteboard images and contents, so far, is not very distinctly defined. For instance, most of the prior enhancement methods generate whiteboards with a completely white background (pixels set to the maximum intensity value) [8, 9, 6] and very saturated pen stroke contents [7], to increase both luminance and color contrast of the whiteboard images as well as the visibility of their pen stroke content. Some other recent methods, on the other hand, tend to choose a less brighter background as well as less saturated pen stroke content [1] for preserving the whiteboard images' original and naturalness appearances. Regardless of such enhancement methods, there hasn't been any other thorough study conducted to investigate the perceptual quality as well as the legibility of whiteboard contents. The effects of the different whiteboard image features on the images' general perceptual quality needs to be studied as well.

Nevertheless, image quality for other natural images have been intensively investigated. We believe that, among the many image quality attributes, naturalness and legibility are the most critical when it comes to whiteboard related applications. Hence, the prior naturalness and legibility studies performed for natural images are briefly summarized in the next section.

As far as we know, none of the prior studies include whiteboard scenes in their experiments and investigations. From our experiences of whiteboard image enhancements, however, the whiteboard image features as well as people's expectations of them are very distinct from that of the other natural images. Therefore, the whiteboard images' quality, particularly the naturalness and legibility attributes, with respect to their image features need to be examined. This type of study is fundamental as well as insightful for the understanding of whiteboard content quality as well as future whiteboard enhancement related researches.

On that account, we have conducted an extended study of whiteboard images' quality. We have investigated the effects of different whiteboard image feature enhancements on the perceived naturalness, legibility as well as overall whiteboard image preference. Different image features such as specularity, brightness levels, lightness contrast, pen stroke color saturation as well as the uniformity of the illumination, have been examined through different sets of psychovisual experiments.

The experiments results indicated that people's requirements from whiteboard images are, somehow, not so different from that of the natural images. Whiteboard images with white and bright backgrounds, higher contrast and colorful pen stroke contents are chosen to be the most legible. On the other hand, the enhancement of the whiteboard images backgrounds found to be negatively affecting the naturalness of the images. The overall investigation, additionally, shows the people's tendency to relay more on legibility of contents than naturalness of whiteboard image backgrounds.

## Naturalness and Legibility of Images

Image quality, according to Runn et al. [10, 11], is defined as a degree to which a given image satisfies sets of requirements which maximizes the naturalness as well as the usefulness of the image. Runn et al. defined the term naturalness as the degree of correspondence between the internal representation of the image and our knowledge or memory of reality. The usefulness of an image, on the other hand, represents the precision of the internal representation of the image which, in turn, determined by the overall discriminability or legibility of the contents of the image.

According to Runn et al., legibility is affected by operations applied on the chroma or luminance contrast attributes of natural images. They have observed an increase in the distances between the image pixels in the CIELuv color space with increasing chroma or brightness contrast level. Increasing distance in a perceptual color space indicates a higher perceived contrast which further provide a more accurate localization and detection of edges. Hence, for increased legibility, the different features of objects in the image has to be exaggerated by increasing the contrast as well as colorfulness of the image [10].

In this work, however, we are considering only whiteboard images. The most important objects/content of whiteboard images will then be the different handwritten texts and illustrations created by different colored and sized whiteboard markers, pen stroke content [1]. Different manipulations on the pen stroke as well as the background of a whiteboard image will then determine the legibility attribute of the overall image quality.

So far, there have been several studies investigating the legibility of hand or computer written characters. The results of the studies show that the discernibility of characters is mainly influenced by different background related factors (such as brightness, color and luminance contrast, display or viewing angle) and other text related factors including the typeface of characters, text size and spacing. Characters with bigger features such as large open counters, easy to recognize shapes, and not excessively bold or light are found to be more legible [12, 13, 14]. Miroljub et al. [15] and other related studies further demonstrated the effects of text and background combinations on written content legibility [16, 17]. They have shown that negative contrast, resulted by dark pen stroke on a white background, makes the writing easily discernable than the positive contrast, generated from white symbols on dark background, due to ease of adaptation. On other studies, however, warm background colors such as Peach, Orange, or Yellow with blue or black pen stroke colors found to be beneficial for increasing legibility and readability than the cool background colors, in particular Blue Grey, Blue, and Green [17].

The other defining attribute of image quality, in addition to the legibility of image contents, is the naturalness of the images. Over the years, several researchers have also been conducting various studies for a better understanding of the naturalness of natural color images. The effects of several factors such as color temperature, hue, chroma, lightness, luminance contrast, saturation, stereoscopic depth, on the naturalness attribute of natural image quality has been investigated thoroughly [10, 11, 18, 19, 20, 21].

According to the results of the prior studies, color temperature and hue changes deteriorate both the naturalness and overall image quality [11, 22]. Increasing other color attributes (such as chroma, saturation, and luminance contrast), on the other hand, up to a certain value, increases the overall quality and naturalness of images and increasing beyond that value have the reverse effect. However, a shift in image quality is observed towards higher chroma, saturation and luminance contrasted images than naturalness; which, in other words, means that observers preferred more colorful and contrasted images even if they look a bit unatural [11, 22, 19, 18]. Andre et al., in another related research for 3D images, shows that introducing more depth enhanced the naturalness of stereoscopic images, but not the image quality [18].

In general, increasing values of some color attributes such as chroma, saturation, and luminance contrast tends to enhance the usefulness/legibility of the contents of the images. For this reason, people preferred more colorful and contrasted images than the ones with a natural appearance. Therefore, one must always compromise on the requirements that he/she need to impose on an image to increase the naturalness or the legibility aspects of image quality.

## Psychovisual Experiment

As explained in the previous sections, image quality for whiteboard like contents is not well investigated and as the result, the purposes of the different whiteboard image enhancement processes get difficult to be specified. Particularly, the most determining whiteboard image features and their effects on the major image quality attributes should be well understood. To better understand whiteboard image quality, we have conducted a serious of psychovisual experiments. Due to the nature of whiteboard image contents, only the naturalness and legibility image quality attributes were selected and investigated with respect to observers' overall quality preferences.

### *Experimental Methodology and Setup*

Prior to our main experiments, we have conducted a categorical judgement based experiments. The experiments were designed with the Subjective Assessment Methodology for Video Quality (SAMVIQ) methodology [23]. In these preliminary experiments, we have tested around 10 types of whiteboard image enhancement results. In the experiments, we were able to observe our observers' muddles for comparing 10 sets of experimental stimuli at a time. We have also seen a discriminability problem in our analysis of the results. To ease the observers' evaluation process and increase the discriminability of the experimental results, we have decided to change the experimental methodology and design to that of the paired comparison techniques [24, 25, 26].

In our main investigation of whiteboard image quality, we have conducted three, paired comparison based, psychovisual experiments. The experiments were designed to independently study the naturalness, legibility and overall quality preference attributes of whiteboard images' quality. In each of the experiment, the observers were presented with pairs of enhanced whiteboard

Table 1: Experimental Instructions

| Experiments | Instructions |
|---|---|
| **Naturalness** | Please chose (click on) the image, which looks more like natural whiteboards to you. Please note that the naturalness should be assessed based on your own personal experience/ memory of the appearances of real-world whiteboards." |
| **Legibility** | "Please chose (click on) the image, which contains more legible contents. Please note that the legibility of contents is determined by how visible and discernible they are." |
| **Quality Preference** | "Please chose (click on) the image, which you think has better perceptual quality. The decision is based on your own personal preference." |

Table 2: Observers' Information

| Experiment | Naturalness | Legibility | Quality preference |
|---|---|---|---|
| **Total No. of observers** | 8 | 11 | 7 |
| **Female** | 4 | 3 | 2 |
| **Age** | 22 to 56 | 25 to 33 | 27 to 35 |
| **Expert** | 4 | 3 | 4 |
| **Display (Color depth)** | 24 bit | 24 bit | 24 bit |
| **Display resolution** | 1536X864 to 3072X1280 | 1280X800 to 2560X1440 | 1476X830 to1920X1200 |

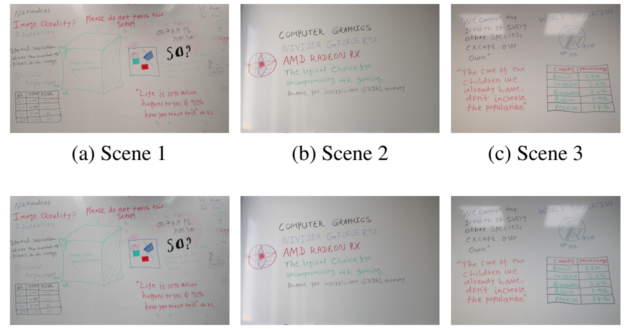
images and asked to select their preference according to the instructions given in Table 1. All our experiments were designed using the QuickEval web application for psychometric scaling experiments [27]. One additional website was also designed by us as an interface among the experimenters, the observers, and the created QuickEval experiments. We have used the website to randomly forward observers to only one of the three experiments as well as collect different observer related information like Table 2.

All the experiments were made available online for volunteer observers and observers were invited to the experiments through e-mail invitations, containing a link to our interface website. To be able to simulate real life streaming based communications, we have allowed the observers to perform the experiments (one observer only one experiment) from their own room and to use their own computers. The necessary observer information, given in Table 2, were gathered remotely through our interface website.

## Experimental Stimuli

The three experiments, described in the previous section, have similar experimental design and experimental stimuli. Their only difference was in the given instructions to the observers, Table 1. We have tried to incorporate different types of whiteboard images, processed with various enhancement methods, as our experimental stimuli. Different background, luminance contrast, brightness, and saturation enhancement methods have been tested.

However, in the paired comparisons type of experiments, every stimulus must be compared with every other stimulus in the selected set of experimental stimuli. The number of comparisons



(a) Scene 1 (b) Scene 2 (c) Scene 3

(d) Corrected 1 (e) Corrected 2 (f) Corrected 3

Figure 1: The original experimental stimuli, representing the three experimental scenes. The images are captured in three different rooms with different lighting conditions. The bottom row images are the white balanced versions of their respective top row images.

to be completed by an observer $N_c$ is then given by Eq. 1, where $n$, $k$, and $t$ represent the total number of stimuli, scenes and replications, respectively [24]. Therefore, for the evaluation of as many whiteboard enhancements as possible with no observers' fatigue, we had to limit the number of evaluated stimuli to $n = 10$, scenes $k = 3$ and replications $t = 1$.

$$N_c = \frac{1}{2}n(n-1)kt \quad (1)$$

The three chosen experimental scenes, captured in three different rooms and illumination conditions, are shown in Fig. 1. Our choices of the acquisition rooms and camera type was made with the intention of simulating the real videoconferencing communications. One of the scenes, Fig. 1b, is captured only with the daylight coming through the class room's side windows and the others (studio and meeting rooms), are captured with the florescent lightings of the respective rooms. All of acquisitions were made using the 16 MP and ultra-wide angle Huddly Go video conferencing camera [28].

The captured whiteboard images, shown from Fig. 1a - 1c, seem to have a colored tint due to the room illumination. Hence, to be able to discount the influences of the illuminations, we have white balanced the images. The illuminant of the images were estimated using the Gray world algorithm [29, 30] and a chromatic adaptation transform is applied to D65 white [31]. The resulted three images, Fig. 1d - 1f are then further processed for different background, contrast, brightness, and saturation enhancement purposes.

## Background Processing

As it is explained in the introduction section, different whiteboard image enhancement methods followed various approaches and goals to enhance the backgrounds of whiteboard images. The main purpose of this study is also to investigate such approaches with respect to whiteboard image quality attributes. Therefore, we have performed around three different background enhancements for each of the white balanced experimental stimuli scene, Fig. 1d - 1f.

- ***White Background***: Most of the state of the art whiteboard enhancement methods process the backgrounds of the images to be completely white. To represent such approaches, we have included one background enhancement method which sets the *RGB* values of the segmented background pixels $P_b$ (from their respective pen stroke pixels $P_p$) to the maximum possible value (255 for 8-bit images), see Fig. 2e.
- ***Specular Highlights removal***: Some state of the art methods, on the other hand, preferred to keep the natural looks of the whiteboard backgrounds rather than setting all the background pixels to white. We have represented such methods by keeping the original background pixel values. However, factors which immensely degrade the visibility of pen stroke content such as specular reflections, shadows and nonuniform illuminations must be illuminated. Therefore, for the removal of specular reflections, we have applied a regionfill algorithm which inpaints the highlight regions by smoothly interpolating inward from the pixel values on the outer boundary of the regions [32]. The specular highlight regions can be detected manually or using other automatic detection methods [33], generating a binary mask of $M$ as shown in Fig. 2b. To be able to recreate the pen stroke content which might have been removed during the inpainting process, the pixel values of the pen stroke content in the original image $I_{original}$ are copied to the newly inpainted image $I_{inpainted}$, $I_{inpainted}(M_p) = I_{original}(M_p)$ where $M_p$ is a binary mask of the pen stroke content. The ratio between the pen stroke pixels and the well exposed background pixels, in their surroundings, of the inpainted image are then later regenerated from those of the original image for better preservation of the pen stroke contrast, based on Eq. 2. The binary mask $M_{p_{big}}$, in the formula, is the enlarged version of the intersection of the specular highlights and pen stroke content binary masks ($M_{p_{big}} = M_p \cap M$), by a dilation process of $5 \times 5$ structuring element. Whereas, the ratio $R_p$ is computed from the input image using Eq. 3. The result of the described regionfill method for one of our experimental scenes can be seen in Fig. 2c.
- ***Uniform Illumination***: In addition to inpainting, we have also corrected the uneven illumination, which occurs due to the nonuniform lighting and orientation of the whiteboards. The prospective type of background subtraction technique, given in Eq. 4, with a background image generated by median filtering $I_{filtered}$ is used for evening out the background illumination [34]. Finally, the ratio of pen stroke pixel values with respect to that of the background pixels are readjusted according to Eq. 2 and 3, similar to the specular removal method. One example result of the illumination correction method is also shown in Fig. 2d.

$$I_{inpainted}(M_p) = \frac{\max\{I_{inpainted}(M_{p_{big}})\}}{R_p} \quad (2)$$

$$R_p = \frac{\max\{I_{original}(M_{p_{big}})\}}{I_{original}(M_p)} \quad (3)$$


(a) Original (b) Binary map of specular regions

(c) Inpainted (d) Inpainted + Illumination correction (e) Set to white

Figure 2: The different background enhancements methods results for one of the scenes of our experimental stimuli. The binary map of the specular highlights given in Fig. 2b is used for our specular removal inpainting method.

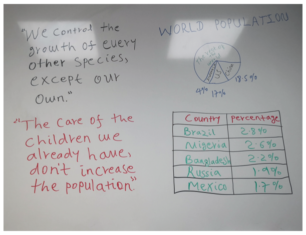
$$I_{uniform} = I_{inpainted} - I_{filtered} + \text{mean}\{I_{filtered}\} \quad (4)$$

### *Brightness and Contrast Enhancement*

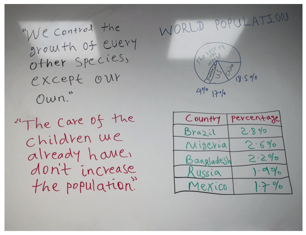
As mentioned in the introduction section, the whiteboard regions of streaming videos are mostly very darker and less contrasted due to all the specular reflections, shadows, camera zooming setups and positions, and other related factors. As a result, besides the background enhancement, brightness and contrast corrections becomes the most important tasks of almost all the whiteboard image enhancement methods. We have also shown that, in our first couple of sections, brighter images with higher luminance contrast tend to be preferred by observers more than the darker alternatives. Therefore, in our experiments, we decided to include the brighter as well as well contrasted versions of all the experimental stimuli that we have generated in the previous sections.

Most of the state of the art whiteboard image contrast enhancement methods mainly depends on a sigmoidal function, with a positive gain factor $gain \in (0,1)$, for globally rescaling the lightness value of the images so that it enhances the darker and suppresses the over-exposed regions of the whiteboard images [10]. However, due to our prior investigation results shown in Fig. 3 and 4, we believe that a combination of exposure correction and local contrast enhancements methods would result in a better, brighter and well contrasted whiteboard images.

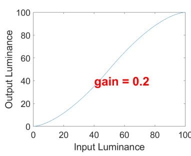
In this regard, we have first applied a histogram-based exposure correction for increasing the brightness of the images without introducing perceptually disturbing over-exposures. To begin with, we have calculated a clipping threshold $\tau$ from the histogram $H$ of the images' luminance channel $L$ ( Fig. 4b) based on the algorithm given in Algorithm. 1, in CIELab color space. $N_{min}$, in the algorithm, represents the minimum number of pixels that we wanted to clip out from the image and is computed as the 1% of the total number of pixels in the image. The variable $N$, on the other hand, contains the total number of the histogram



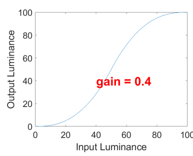

(a) Enhanced = 0.2



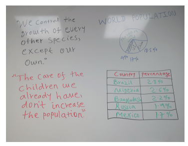
(b) Enhanced = 0.4




(c) gain = 0.2




(d) gain = 0.4



(e) Original

Figure 3: Global contrast enhancement results with a sigmodal function of different gain factor values [10].

bins. The resulted value of $\tau$ is then used to clip and expand the luminance values of the input image to the maximum possible value (which is usually considered to be 100 in the CIELab color space), according to Eq. 5. Finally, the contrast of the resulted images are further locally improved using the Contrast-Limited Adaptive Histogram Equalization (CLAHE) based local contrast enhancement method [35], see Fig. 4c and 4d.

**Algorithm 1** Threshold detection for exposure correction

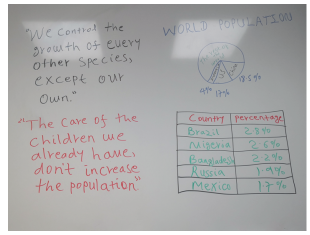
**procedure** COMPUTE THRESHOLD
  $N_{min} \leftarrow \sum H \times 0.01$
*loop*:
  **if** $H(N) < N_{min}$ **then**
    $\tau \leftarrow H(N)$. **Break**
  **else**
    $N \leftarrow N - 1$.
  **goto** *loop*.
  **close**;

$$L > \tau = \tau \qquad then, \qquad L_{new} = \frac{L}{\tau} 100 \tag{5}$$

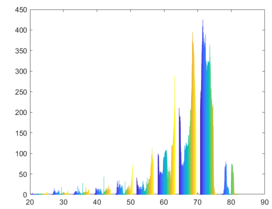
### *Saturation Correction*

In different natural images as well as whiteboard images processing's, increasing or expanding the lightness or the brightness of an image usually leads to the desaturation of the colors of its contents [36]. Moreover, as described in our first sections, images with more colorful and vivid appearance have been the choices of many observers. Hence, most whiteboard and natural image enhancement methods tend to boost the saturation of colored contents. Similarly, for our experiment, we too have included saturated images of the brightness and contrast enhanced images from the previous section (Fig. 5).

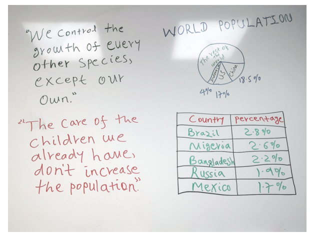
The color saturations of the images were amplified by linearly scaling the chroma channel of the given image, in



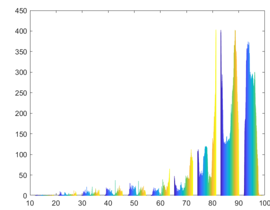
(a) Original



(b) Luminance histogram



(c) Enhanced image



(d) Corrected luminance histogram

Figure 4: Example result of our histogram based exposure correction and local contrast enhancement. Both the input and enhanced images with their respective luminance channel histograms are presented side by side.

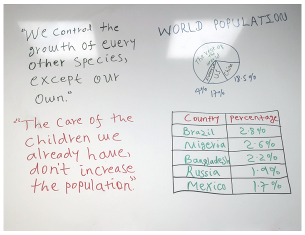
CIELab color space. Chroma of the image's pixels can be computed from their $a^*$ and $b^*$ channels of CIELAB space values, $\sqrt{(a^*)^2 + (b^*)^2}$. We have tested a number of constant values (ranging from 1 to 5) for scaling the chroma values of a number of images and the value of 2.5 have been chosen for its good saturation enhancement results with les hue changes, see Fig. 5. Scaling chroma with values greater than 2.5 sometimes, depending on the image content, leads to unpleasant hue changes.

## Results and Discussion

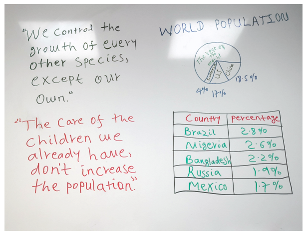
To better understand the different features of the good whiteboard image quality, three psychovisual experiments have been conducted. A total of 30 experimental stimuli, 3 types of scenes (shown in Fig. 1) processed with 10 different enhancement methods (described in the previous section and Table. 3), have been evaluated in each of the experiments. The total number of observers who have been successfully completed the experiment as well as the related observers' information is provided in Table. 2.

The observers' pairwise comparison results in each of the experiments are separately analyzed, following the pairwise comparison analysis guide proposed by Pérez et al. [25]. The preferences of the observers are first converted into comparison matrixes and presented as heatmaps in Fig. 6. The columns and rows of the maps indicate the evaluated 9 experimental stimuli, excluding the original stimuli. Please refer to the provided label numbering in Table. 3 and Fig. 6 to make the correspondence. The numbers in the small squares of the maps represent the total number of times that the stimulus in the corresponding raw is selected as better than the stimulus in the corresponding column. Note that each heatmap contains the sum of the observers vote counts for the evaluated three types of scenes, Fig. 1.

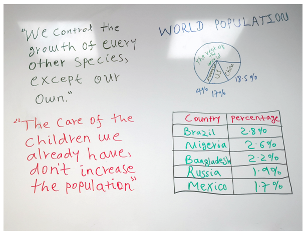
Comparison matrixes are always in ordinal scale and they cannot clearly show the magnitude of the quality differences be-



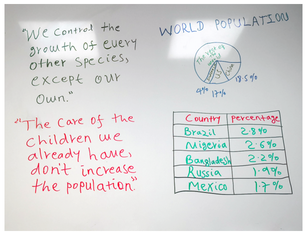

(a) *Chroma* × 1




(b) *Chroma* × 1.5




(c) *Chroma* × 2.0

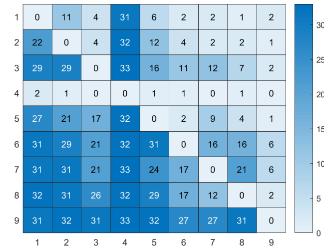



(d) *Chroma* × 2.5

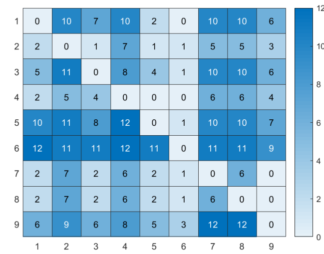
Figure 5: Example result of the saturation enhancements by linearly scaling the chroma channel of the brightness and contrast enhanced stimuli.

Table 3: The 10 enhancements of the experimental stimuli and their corresponding variable descriptions.

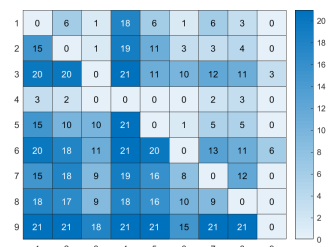
| **Variable** | **1. stm1** | **2. stm2** | **3. stm3** | **4. stm4** | **5. stm5** |
|---|---|---|---|---|---|
| **Description** | Inpainted image (see Fig. 2c) | stm4 with additional uniform illumination, brightness and contrast enhancement | stm2 with saturation enhancement | stm1 with additional nonuniform illumination correction(see Fig. 2d) | stm10 with brightness and contrast enhancement (see Fig. 4) |
| **Variable** | **6. stm6** | **7. stm7** | **8. stm8** | **9. stm9** | **10. stm10** |
| **Description** | stm5 with saturation enhancement (see Fig. 5) | stm10 with background set to maximum white (see Fig. 2e) | stm7 with brightness and contrast enhancement | stm8 with saturation enhancement | The white balanced original image (see Fig. 1) |




(a) Legibility




(b) Naturalness



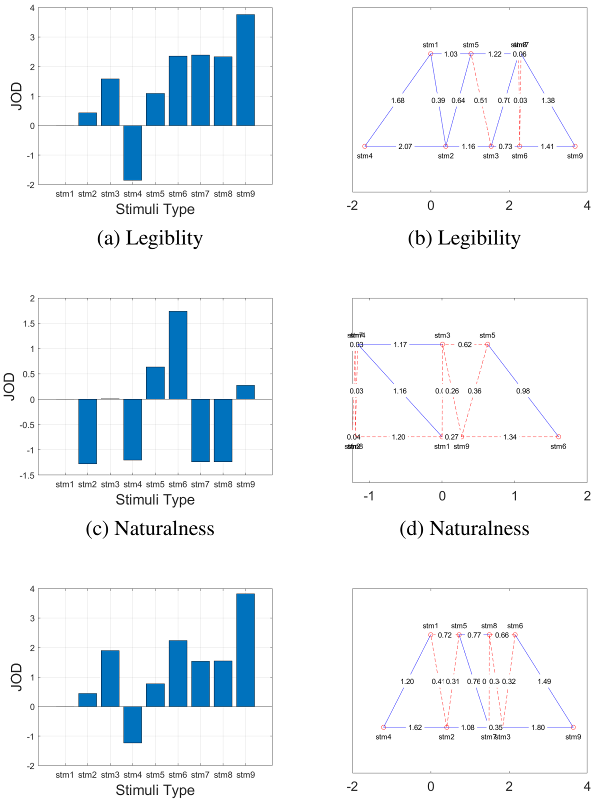

(c) Quality preference

Figure 6: Heatmaps of the comparison matrixes computed from the results of the three experiments. The vertical and horizontal labels of the matrixes correspond to the numbering of the experimental stimuli provided in Table. 3. The comparison matrix of the individual experiment, contains the sum of the matrixes of the three experimental scenes (Fig. 1).

tween the stimuli. Interval scales, on the other hand, can incorporate the order as well as the magnitude of the differences between the stimuli. To convert our raw comparison matrixes into interval scale quality scores, we have performed pairwise comparison scaling, based on Thurstone's model V. For more detail description of the scaling method, please refer to Pérez et al. [25]. The Pérez et al.'s method scales the comparison values in Just-Objectionable-Difference (JOD) units rather than Just-Noticeable-Differences (JNDs), where 1 JOD indicates that the 75% of our observers can see the difference between the two stimuli. The JOD results of our three experiments are presented in Fig. 7a, 7c and 7e.

However, according to Pérez et al. [25], the confidence interval measurements computed from the scaling JOD units should not be used to infer statistical significance of the difference magnitudes. Instead, it is recommended to use resampling techniques. For visualizing the statistical significance of our results, presented so far, we have applied the bootstrapping based resampling technique, proposed by Pérez et al. [25]. From our experimental results, the method generates plots like Fig. 7b. The continuous lines in this plot, indicate statistically significant differences between the pairs of the conditions and the dashed lines indicate the lack of evidence for statistically significant differences.

As it can be seen from the presented results, so far, experimental images with white backgrounds together with higher brightness, contrast and saturation are considered to be more legible (stim7 - 9). These same stimuli, additionally, were preferred by most of our observers in terms of image quality. The quality differences of the white background whiteboards with enhanced brightness, contrast as well as saturation (stim9) to that of the other evaluated whiteboard images were statistically significant. In the contrary, whiteboard images for which we have only removed the specular highlights and corrected the non-uniform illuminations (stim4) are considered the most illegible and low quality images. See Fig. 7a, 7b, 7e, 7f.




(a) Legiblity (b) Legibility

(c) Naturalness (d) Naturalness

(e) Quality preference (f) Quality preference

Figure 7: Paired comparison scaling results of our three experiments.

Nevertheless, among the evaluated quality attributes, the naturalness evaluation results show a little deviated behavior than the others. As we can see from the results presented in Fig. 6b, 7c, and 7d, the whiteboard images with no background processing (stim5 and 6) are chosen to be more natural than the other images. One should also note that the legibility and overall quality preferences of the two images were also comparable to the other best performing stimuli.

Moreover, the correlations of our legibility and overall quality preference experimental results shows us that when it comes to whiteboard image quality, it is mostly the legibility attribute which plays the most important role in determining the overall quality. Our observers show a tendency of choosing a whiteboard image with more discernible pen stroke content, even though its background looks unnatural. The appearance attributes such as brightness, contrast and saturation are also been found to be the most significant quality factors than the naturalness of the whiteboard backgrounds.

## Conclusion

In this work, we have studied whiteboard image quality with respect to different enhancement ideas. Quality attributes such as naturalness, legibility as well as observers' quality preferences were examined with respect to previous studies on natural images. We have evaluated several whiteboard image backgrounds, brightness, luminance contrast as well as saturation enhancement approaches. Our results, generally, showed that observers' quality preference from whiteboard images is almost similar with that of the natural images. In the assessment of whiteboard image quality, the legibility of the pen stroke content was found to be more significant than the naturalness of the background. Enhancements of color attributes such as brightness, contrast, and saturation, leads to increased legibility, naturalness as well as overall quality preferences of whiteboard images.

## References


[1] C. A. A. Duque, M. A. Abebe, M. Shahid, and J. Y. Hardeberg, "Color and quality enhancement of videoconferencing whiteboards," *Electronic Imaging*, vol. 2018, no. 16, pp. 010 504–1–010 504–13, 2018. [Online]. Available: https://www.ingentaconnect.com/content/ist/ei/2018/00002018/00000016/art00003

[2] H. Lu and M. Kowalkiewicz, "Text segmentation in unconstrained hand-drawings in whiteboard photos," in *International Conference on Digital Image Computing Techniques and Applications (DICTA)*, Dec 2012, pp. 1–6.

[3] T. Plotz, C. Thurau, and G. A. Fink, "Camera-based whiteboard reading: New approaches to a challenging task," in *International Conference on Frontiers in Handwriting Recognition*, Montreal, Canada, 2008, pp. 385 – 390.

[4] M. Wienecke, G. A. Fink, and G. Sagerer, "Towards automatic video-based whiteboard reading," in *Seventh International Conference on Document Analysis and Recognition, 2003. Proceedings.*, Aug 2003, pp. 87–91 vol.1.

[5] S. Vajda, L. Rothacker, and G. A. Fink, *A Method for Camera-Based Interactive Whiteboard Reading*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 112–125.

[6] Z. Zhang and L.-W. He, "Whiteboard scanning and image enhancement," *Digital Signal Processing*, vol. 17, no. 2, pp. 414 – 432, 2007.

[7] M. Gormish, B. Erol, D. G. Van Olst, T. Li, and A. Mariotti, "Whiteboard sharing: capture, process, and print or email," pp. 78 790D–78 790D–9, 2011.

[8] L. W. He, Z. Liu, and Z. Zhang, "Why take notes? use the whiteboard capture system," *Technical Report MSR-TR-2002-89, Microsoft Research*, September 2002, [Online; accessed 12-April-2017].

[9] L. W. He and Z. Zhang, "Real-time whiteboard capture and processing using a video camera for remote collaboration," *IEEE Transactions on Multimedia*, vol. 9, no. 1, pp. 198–206, Jan 2007.

[10] R. Janssen, *Computational Image Quality*, R. Janssen, Ed. SPIE PRESS, Jun. 2001, vol. PM101.

[11] T. Janssen and F. Blommaert, "Predicting the usefulness and naturalness of color reproductions," *Journal of Imaging Science and Technology*, vol. 44, no. 2, pp. 93–104, 2000.

[12] D. W. Andersen, "What makes writing legible?" *The Elementary School Journal*, vol. 69, no. 7, pp. 365–369, 1969. [Online]. Available: https://doi.org/10.1086/460524

[13] A. Haley, "It's about legibility," *Monotype Imaging Inc*, 2017.

[14] T. Zlokazova and I. Burmistrov, "Perceived legibility and aesthetic pleasingness of light and ultralight fonts," in *Proceedings of the European Conference on Cognitive Ergonomics 2017*, ser. ECCE 2017. New York, NY, USA: ACM, 2017, pp. 191–194. [Online]. Available: http://doi.acm.org/10.1145/3121283.3121296

[15] M. Grozdanovic, D. Marjanovic, G. L. Janackovic, and M. Djord-

jevic, "The impact of character/background colour combinations and exposition on character legibility and readability on video display units," *Transactions of the Institute of Measurement and Control*, vol. 39, no. 10, pp. 1454–1465, 2017. [Online]. Available: https://doi.org/10.1177/0142331216640601

[16] P. KEMBER and D. VARLEY, "The legibility and readability of a visual display unit at threshold," *Ergonomics*, vol. 30, no. 6, pp. 925–931, 1987. [Online]. Available: https://doi.org/10.1080/00140138708969788

[17] L. Rello and J. P. Bigham, "Good background colors for readers: A study of people with and without dyslexia," in *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS '17. New York, NY, USA: ACM, 2017, pp. 72–80. [Online]. Available: http://doi.acm.org/10.1145/3132525.3132546

[18] A. Kuijsters, W. A. IJsselsteijn, M. T. M. Lambooij, and I. Heynderickx, "Influence of chroma variations on naturalness and image quality of stereoscopic images," in *Human Vision and Electronic Imaging XIV, part of the IS&T-SPIE Electronic Imaging Symposium, San Jose, CA, USA, January 19-22, 2009, Proceedings*, 2009, p. 72401. [Online]. Available: https://doi.org/10.1117/12.817749

[19] H. de Ridder, "Naturalness and image quality: Saturation and lightness variation in color images of natural scenes," *Journal of Imaging Science and Technology*, vol. 40, no. 6, pp. 487–493, Nov. 1996.

[20] R. Halonen, S. Westman, and P. Oittinen, "Naturalness and interestingness of test images for visual quality evaluation," pp. 7867 – 7867 – 12, 2011. [Online]. Available: https://doi.org/10.1117/12.872390

[21] ——, "Naturalness and interestingness of test images for visual quality evaluation," *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 7867, 01 2011.

[22] E. A. F. Huib de Ridder, Frans J. Blommaert, "Naturalness and image quality: chroma and hue variation in color images of natural scenes," pp. 2411 – 2411 – 11, April 1995. [Online]. Available: https://doi.org/10.1117/12.207555

[23] F. Kozamernik, V. Steinmann, P. Sunna, and E. Wyckens, "SAMVIQ—a new EBU methodology for video quality evaluations in multimedia," *SMPTE Motion Imaging Journal*, vol. 114, no. 4, pp. 152–160, April 2005.

[24] R. Christensen, "The method of paired comparisons," *Technometrics*, vol. 31, no. 4, pp. 495–496, 1989. [Online]. Available: https://www.tandfonline.com/doi/abs/10.1080/00401706.1989.10488612

[25] M. Pérez-Ortiz and R. Mantiuk, "A practical guide and software for analysing pairwise comparison experiments," 12 2017.

[26] D. A. Silverstein and J. E. Farrell, "Efficient method for paired comparison," *Journal of Electronic Imaging*, vol. 10, no. 2, pp. 394–399, Apr. 2001. [Online]. Available: https://www.spiedigitallibrary.org/journals/Journal-of-Electronic-Imaging/volume-10/issue-2/0000/Efficient-method-for-paired-comparison/10.1117/1.1344187.short

[27] V. N. Khai, J. J. Storvik, A. D. Christopher, F. Ivar, and P. Marius, "Quickeval: A web application for psychometric scaling experiments," vol. 9396, 02 2015.

[28] (2017) Huddly go wide angle videoconferencing camera. Huddly. [Online]. Available: https://www.huddly.com/

[29] M. Ebner, *Color Constancy*. John Wiley & Sons, 2007.

[30] J. Cepeda-Negrete and R. E. Sanchez-Yanez, "Gray-world assumption on perceptual color spaces," in *Image and Video Technology*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 493–504.

[31] S. Westland, C. Ripamonti, and V. Cheung, *Chromatic-Adaptation Transforms and Colour Appearance*. John Wiley & Sons, Ltd, 2012, ch. 6, pp. 75–92. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9780470710890.ch6

[32] MATLAB. (2018) regionfill. MathWorks. [Online]. Available: https://www.mathworks.com/help/images/ref/regionfill.html

[33] M. A. Abebe, A. Booth, J. Kervec, T. Pouli, and M.-C. Larabi, "Towards an automatic correction of over-exposure in photographs: Application to tone-mapping," *Computer Vision and Image Understanding*, vol. 168, pp. 3 – 20, 2018, special Issue on Vision and Computational Photography and Graphics. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1077314217300954

[34] R. Clouard. (2011, Jul.) Illumination correction. Pantheon Project. [Online]. Available: https://clouard.users.greyc.fr/Pantheon/experiments/illumination-correction/index-en.html

[35] K. Zuiderveld, "Graphics gems iv," P. S. Heckbert, Ed. San Diego, CA, USA: Academic Press Professional, Inc., 1994, ch. Contrast Limited Adaptive Histogram Equalization, pp. 474–485. [Online]. Available: http://dl.acm.org/citation.cfm?id=180895.180940

[36] M. Fairchild, *Color Appearance Models*, ser. The Wiley-IS&T Series in Imaging Science and Technology. Wiley, 2005. [Online]. Available: https://books.google.no/books?id=8_TxzK2B-5MC