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Next Generation Personalized Display Systems Employing Adaptive Dynamic-Range Compression Techniques to Address Circadian Rhythm and Personal Behaviors

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ABSTRACT

Reproducing fidelitous images, those that include the individual impressions induced when the real scene is viewed, is important. Our previous studies and other physiological research results suggest that the human visual system characteristic dynamically changes depending on circadian rhythm and personal behavior. This paper describes these findings and future issues.

1 Introduction

In the real world, human observers perceive various objects under a wide range of luminance values from low to high; sunlight at noon can be $10^{8.5}$ times more intense than star-light [1]. Although the dynamic range that can be perceived simultaneously by human observers (e.g., more than approximately $10^{3.5}$ in our previous experiment in a laboratory room [2]) is much less than the above mentioned value, it is still much greater than that of a Standard-Dynamic-Range (SDR) display (i.e., approximately 10^2). Images that try to reproduce the same range end up looking overexposed, underexposed, or both. This is because our visual systems can capture a full range of tones in high contrast scenes. To achieve greater realism, High-Dynamic-Range (HDR) technologies are emerging in not only the display field, but also television system standards, i.e., Recommendation ITU-R BT. 2100 [3]. In order to display HDR images or videos, quite dark rooms are conventionally required to avoid the picture quality degradation caused by viewing flare from illumination sources in the room [2][4]. The next step is, therefore, converting HDR images/videos into SDR images/videos that retain their Perceptual Reality (PR), i.e., reducing the impairments caused by flare, so HDR contents can be comfortably viewed in daily life often [2][4].

Tone Mapping Operators (TMOs) are now being used to compress HDR into SDR images. Many types of methods employing either Local- or Global- TMOs have been proposed [5]. Tone mapping performance comparisons of proposals based on deep learning have also been made [6]. Three examined methods that employ Local-TMO [7]-[9], and two methods that employ Global-TMO [10]-[11] were selected as the best five from among twenty-four methods tested; this suggested they were nearly comparable. Here, note that all selected methods are based on models, not real human visual perception or evaluations.

Our previous studies [2][4] examined the appearance of images at high levels of contrast. We first identified the perceived change in luminance sensitivity as indicated by human observers (i.e., Weber-ratio), and then generated SDR images using only the Global-TMO indicated by image processing to reproduce the appearance of the HDR images.

2 Introduction of our recent approach: SDR image reproduction from HDR image considering circadian rhythm

In the next stage, as shown in Fig. 1, we showed the concept of converting real HDR stimuli into normalized visual percept (NVP), which can be recorded within SDR (i.e., CR is approx. 100:1) with preserved perceptual reality or natural tone [12]. Note that, in the conversion process, the human visual system probably employs just a few transfer functions when processing HDR stimuli into their inner perception equivalents for memorization, depending on the context, e.g., sunny, cloudy, and night. We named this effect the "circadian-condition reflection".

Supplementing the above mentioned study results, N. Kubota, et al. [13] recently revealed that a head-mounted device with different light incident angles (55° vs. 28°) altered (1) the magnitude of nocturnal melatonin suppression, i.e., lower angle was significantly effective, and (2) light-evoked

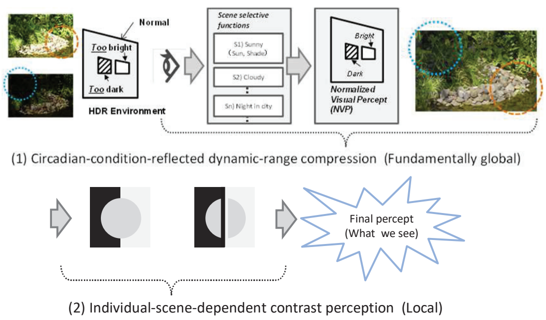


Fig. 1 Our hypothesis of two-step human visual perception: (1) In the first step, human visual system only employs scene-independent Global-TMO for image information compression from HDR real scene to input percept for next sages (Note that people cannot perceive this image directly). (2) In the second step, i.e., complex stages after the early vision, individual-scene-dependent Local-TMOs are employed. [12]

pupillary constriction mediated by ipRGCs, i.e., lower angle significantly greater, in healthy young subjects.

This suggests that (1) the morning sun light affects the human visual system directly via photoreceptor cells in the eyes, and (2) the validity of our proposed hypothesis that the human visual system may control its perceived contrast transfer function according to the lighting condition changes that occur in the circadian cycle with the trigger being morning sun light.

Therefore, we directly use the terminology of "circadian rhythm" from now on [14] [15].

3 Recent experiment: individual differences in perceptual tone in relation to image capturing time and differences in discrimination ability

The following study showed that circadian rhythm strongly depends on the individual's visual experiences in daily life [14][15]. Experiments also revealed that some observers with sensitive vision were able to discriminate capture time, not the actual capture time but the simulated capture time based on tone mapping, with significant difference ($p < .05$); the other observers could not achieve this level of discrimination. That is, they judged the time based on the difference in tone mapping curves (i.e., gradation). Cluster analysis of further results suggested that (1) gradation-sensitive and insensitive groups are generally separated, but they are in spectrum, (2) there are individual-specific differences in significant tone-mapping pairs, (3) especially in early-morning and/or morning conditions, there existed two opposite-types of individuals who prefer high- or low- contrast, which was reflected the difference in daily personal behavior. Details are as follows.

3.1 Experimental procedures

Evaluation items: Four experiments were conducted to assess perceptual similarity among "early-morning (EM)", "morning (MG)", "afternoon (AN)", and "late-afternoon (LA)" scenes; the paired comparison method was employed [16].

Experimental environment: A 24-inch LCD sRGB color display (EIZO ColorEdge CS2410) was employed in a light room with natural ambient LED lights, which gave a normal illuminance of approximately 300 lx at the display surface. Display resolution was 1920 x 1200. Maximum white luminance was approximately 120 cd/m^2, with approximate contrast ratio of 100:1 or more. Viewing distance was approx. 60 cm.

Stimuli: Nine kinds of images taken in either early-morning or late-afternoon for EM/LA discrimination experiments, and nine kinds of images taken in either morning or afternoon for MG/AN discrimination experiments were selected.

All original images were taken by Nikon SDR cameras (D500 or D800E) with 14-bit luminance resolution (i.e., HDR raw images), and SDR images used in the evaluation were converted from HDR by using our proposed method [12].

Subjects: A total of 24 subjects participated (17 males and 7 female) ages ranged from 20- to 60-year-old of age. All were confirmed as CNOs by Ishihara test.

Subjective evaluation task: Participants were required to judge naturalness in each pair of images by using five grade comparison scale (A: +2, –, even: 0, –, B: -2) under given

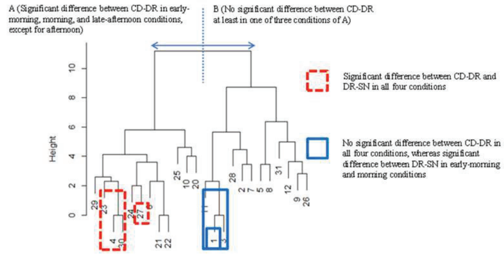


Fig. 2 Cluster analysis result 1 (by binary state)

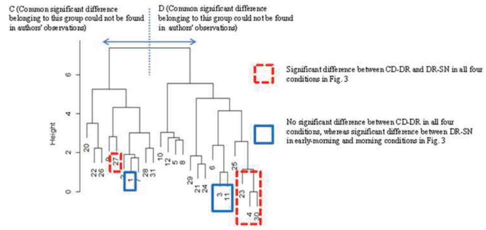


Fig. 3 Cluster analysis result 2 (comparison to Fig. 2)

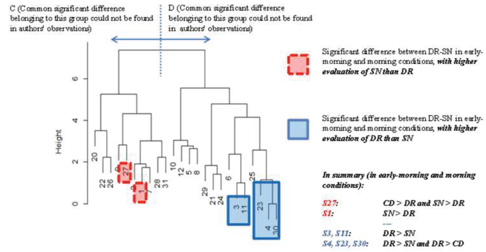


Fig. 4 Cluster analysis result 2 (summary)

mental set (i.e., one of EM, MG, AN, or LA).

3.2 Results and discussions

Actual image capture time versus perceived time: Analysis of the paired comparison test results revealed that some observers with sensitive vision were able to discriminate capture time, not the actual capture time but the simulated capture time based on tone mapping, with significant difference ($p < .05$); the other observers could not achieve this level of discrimination. That is, they judged the time based on the difference in tone mapping curves (i.e., gradation).

Comparison of two kind cluster analyses: We subjected the paired comparison test results to two cluster analyses. First, observer classification based on discrimination ability. In this case, the input data of each observer was created based on significant difference between methods A and B (1) or no-significance (0). The other classified observers based on favorite tone curve. In this case, the input data of each observer was created based on significant preference for method A (+1), no significance, method B was significantly preferred (-1).

Figures 2 to 4 show analysis results. In summary, the results of the two cluster analyses suggest that (1) gradation-sensitive and insensitive groups were generally separated, but their distribution was in spectrum, (2) there were individual differences in significant tone-mapping pairs, (3) especially in early-morning and/or morning conditions, two opposite-types of individuals existed who preferred high- or low- contrast, that was reflected the difference in individual daily visual behavior.

4 Introduction of our current findings: hidden relationship suggested between imperceptible- and perceptible- effects in circadian rhythm individuality by sunlight or other illuminations

Here we also consider well-known “circadian rhythm” from the physiological point of view in addition to our psychophysical experimental results.

4.1 Imperceptible illuminance effects in circadian rhythm individuality suggested by physiological research [17]-[20]

Fist, S. Higuchi (2013) described “Physiological polytypism is very difficult keyword, but it is important to clear this keyword” from the point of “Non-visual effects of light and circadian rhythm” [17].

In individual research, for example, M. Takao et al. (2009) demonstrated that neither photoperiod nor season of birth modulated diurnal preference in the Japanese population [18], even though diurnal preference in Canadian populations was modulated by the season of birth [19]. These suggested that these ethnic differences might characterize the circadian photosensitivity in infancy. It was also reported that two biological differences are reported to exist between Caucasians and Asians: polymorphisms of circadian clock genes and difference in ocular photosensitivity.

In addition to the above discussion regarding the effects induced by melatonin, recently, M. Saito (2018) revealed that the effects of ipRGC (intrinsically photosensitive retinal ganglion cell), which contains melanopsin, inside the blind spot (i.e., scotoma) affected luminosity sensitivity threshold of other visible parts [20].

4.2 Perceptible illuminance effects in circadian rhythm individuality: Summary of our current supplementary experiments [21]

In summary, our experimental results suggested that NVP variation due to individuality clearly existed in both morning and afternoon and combination was also widely scattered by cluster analysis (See Fig. 5). Details are as follows.

Preparation: We newly introduced a set of five NVPs, for daytime outside scenes, as shown in Fig. 6. TC-1 represents most dark and high-contrast conversion and TC-5 represents most bright and low-contrast conversion, vis a versa （See also Fig. 8 (a) for confirmation of converted images from HDR to SDR）.

Both the illuminant displayed image and the image printed on photo-matte paper were available for observation. Note that a set of special compensations was needed in producing the printed version, dependent on AM or PM, as shown in Fig. 7 （See also Fig. 8 (b) for confirmation of converted images from HDR to SDR）.

Stimuli: As shown in Fig. 9, total of six kinds of images taken in either morning (#101-#103) or early-afternoon (#201-#203) were presented by either displayed or printed images, depending on observer’s convenience (Except for one participant, printed image was chosen). In case of printed image, the size was ISO 216 “A4”. In the case of display, viewing condition was free in office room.

Subjects: All participants (total number was 29; 20 males and 9 females), whose ages was ranged from 19-year-old to more aged social adults (where we did not acquire accurate age for keeping their privacy in case of social adults) were confirmed as CNOs by Ishihara test. They were separated into three groups: (a) college student group living in Kagoshima area, aged under 26, (b) social adult group-1 living in Kagoshima-area, or (c) social adult group-2 living in Kanazawa-area, both aged over 28.

Subjective evaluation task: Subjective evaluation task: Participants were required to choose which image was perceived most natural image among five different NVP images after comparing freely without viewing-time- or viewing-distance- limitation, where they also required that they imagined the environment situation was morning very clear sunny day for observing #101-#103, or early-afternoon very clear sunny day for observing #201-#203. They were also required to report it if they were not able to choose one.

4.3 Discussions

We have newly discovered that both perceived luminance tones (depending on both brightness and contrast) and those combination of AM and PM are widely scattered by person. It is also suggested that the variety of cumulative lifestyles has impact similar to the discussion of physiological circadian rhythm analyses, from additional questionnaires.

These findings suggest a hidden relationship between imperceptible- and perceptible- effects in circadian rhythm individuality by sunlight or other illumination, contrary to current common understanding.

5 General discussions

Generally speaking, visual illusions offer good cues for elucidating about how perception normally works and why it sometimes fails [22]. “The dress” is also a popular and symbolic example of individual differences in color perception in ambiguous conditions, and it is suggested that this phenomenon is based on individual differences in daily life, i.e., people who prefer outside have a tendency to focus color judgement on bright parts, whereas people who prefer inside focus on the dark parts [23].

The above results offer exciting new examples. The authors think that these phenomena should be examined more precisely under the scientific approach and apply the results to yield personalized image capture/exchange for industry. This should allow personalized image realism before text-based scene description.

The future works need to be carried more systematically through the cooperation of many basic researchers and industrial companies.

6 Conclusions

Reproduction of fidelitous videos/images, where individual impressions are induced by the time at which the real scenes were captured, is important. Our previous study suggested that the characteristics of the human visual system dynamically

Fig. 5 Cluster analysis result

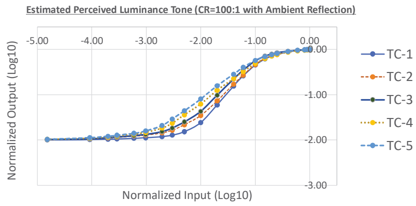


Fig. 6 Newly employed NVPs (TC-1 - TC-5)

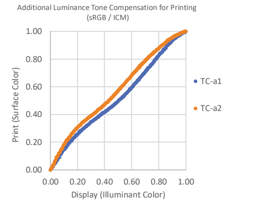
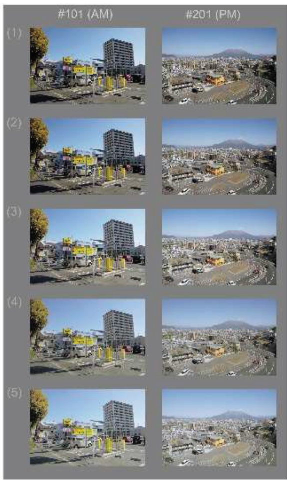
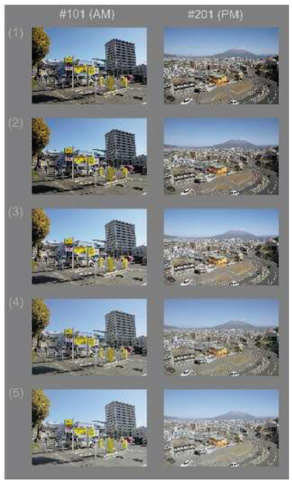


Fig. 7 Compensations for printing (TC-a1 for AM and TC-a2 for PM)



(a) For illuminant display image observation



(b) For printed image observation

Fig. 8 Demonstration of changing Tone (#101: captured in morning, and #201: captured in afternoon)

(a) #101 (b) #102 (c) #103 (d) #201 (e) #202 (f) #203

Fig. 9 Experimental stimuli (AM: #101 - #103, and PM: #201 - #203). Images are for display observation.

change following the individual's circadian pattern in general. This study newly suggests that they significantly depend on individuality i.e., personal behavior.

Our experiments strongly suggest the existence of a new research field important to both academia and industry.

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References

[1] N. Ohta, et al.: "Colorimetry: Fundamentals and Applications," Wiley, 2005.

[2] S. Iwaida, et al.: "Reproduction of Perceptual Reality in Standard-Dynamic-Range (SDR) Environments Using High-Dynamic-Range (HDR) Images Compressed by Global Tone Mapping," SID Symposium Digest of Technical Papers, Vol. 48 (1), P-216L: Late-News Poster, pp. 1379-1382, 2017.

[3] https://www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.2100-2-201807-I!!PDF-E.pdf, retrieved Jan. 6, 2022.

[4] Y. Fukaya, et al.: "Reproduction of Perceptual Reality in Standard-Dynamic-Range (SDR) Environments Using High-Dynamic-Range (HDR) Images Compressed by Global Tone Mapping: Further Analysis and Subjective Evaluation of Reproduced Images," Proceedings of the International Display Workshops, Vol. 25 (IDW2018), VHFp1-1, pp. 1054-1057, 2018.

[5] E. Reinhard, et al.: "High Dynamic Range Imaging (2nd Edition): Acquisition, Display, and Image-Based Lighting," Elsevier, 2010.

[6] H. Sasaki, et al.: "Automatic Selection of Preferable Tone-Mapping Method based on Deep Learning," Proceedings of the International Display Workshops, Vol. 26 (IDW2019), AISp2/VHFp6-1, pp. 47-50, 2019.

[7] E. Reinhard, et al.: "Photographic Tone Reproduction for Digital Images," ACM Transactions on Graphics, vol. 21, no. 3, pp. 267-276, 2002.

[8] M. Ashikhmin: "A Tone Mapping Algorithm for High Contrast Images," Eurographics Workshop on Rendering, pp. 1–11, 2002.

[9] Y. H. Yee, et al.: "Segmentation and adaptive assimilation for detail-preserving display of high-dynamic range images," The Visual Computer, vol.19 (7-8), pp.457-466, 2003.

[10] P. Ferschin, et al.: "A comparison of techniques for the transformation of radiosity values to monitor colors," Proceedings of 1st International Conference on Image Processing, vol. 3, pp. 992-996, 1994.

[11] F. Drago, et al.: "Adaptive Logarithmic Mapping for Displaying High Contrast Scenes," Computer Graphics Forum, vol. 22, no. 3, pp. 419-426, 2003.

[12] S. Ohtsuka, et al.: "Human visual system uses just a few transfer functions depending on various environments to realize normalized visual percept: investigation using real photographic images," SID Symposium Digest of Technical Papers, Vol. 51 (1), 80-4, pp. 1202-1205, 2020.

[13] N. Kubota, et al.: "Effects of different light incident angels via head-mounted device on the magnitude of nocturnal melatonin suppression in healthy young subjects," Sleep and Biological Rhythms, pp. 8, Published online, Jan. 2022, https://doi.org/10.1007/s41105-021-00360-7.

[14] Y. Orita, et al.: "Visually Fidelitous Dynamic-Range Compression from HDR Images: Dependency of Individual on Perceived Time by Observing Images Reproduced with Global Tone Mapping Curves," IEICE Technical report, Vol. 121 (211), HIP2021-46, pp. 87-92, 2021(in Japanese).

[15] S. Iwaida, et al.: "Importance of Individual Adaptation in Visually Fidelitous Dynamic-Range Compression from HDR to SDR Images," SID Symposium Digest of Technical Papers, Vol. 53 (1), 68-3, pp. 914-917, 2022.

[16] S. Nakaya, "A Modification of Scheffe's Method for Paired Comparisons," Procedure of the 11th Meeting of Sensory Test, pp. 1-12, 1970 (in Japanese).

[17] S. Higuchi: "Non-visual effects of light and circadian rhythm: approach to physiological polytypism," Japan Society of Physiological Anthropology, vol.18, No.1, pp.39-43, 2013 (In Japanese, Abstract in English) (DOI: https://doi.org/10.20718/jjpa.18.1_39).

[18] M. Takao, et al.: "Photoperiod at birth does not modulate the diurnal preference in Asian population," Chronobiology International, no.26, vol.7, pp.1470-1477, 2009.

[19] V. Mongrain, et al.: "Contribution of the photoperiod at birth to the association between season of birth and diurnal preference," Vol. 406, No. 1-2, pp.113-116, 2006.

[20] M. Saito, et al: "Invisible light inside the natural blind spot alters brightness at a remote location," Scientific Reports, vol. 8, 9 pages, 2018 (DOI: https://doi.org/10.1038/s41598-018-25920-9).

[21] S.Iwaida, et al: "Deriving Adaptive Image Reproducing Tone Curves to Fit Human Visual Perception in Natural Environments－Image Quality Evaluation Considering Circadian Rhythm and Individuality－," IIEEJ MCC2022, G4-2, 2022 (in Japanese).

[22] R. L. Gregory: "Eye and Brain: The Psychology of Seeing (fifth edition)," Oxford University Press, 1998.

[23] P. Wallisch: "Illumination assumptions account for individual differences in the perceptual interpretation of a profoundly ambiguous stimulus in the color domain: "The dress"," Journal of Vision, Vol. 17 (4):5, pp. 1-14, 2017.