CIC28 ONLINE

Twenty-eighth Color and Imaging Conference

4-19 November 2020

FINAL PROGRAM AND PROCEEDINGS

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held online November 4-19, 2020.

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WELCOME TO CIC28!

We should be saying "Welcome to Chiba for a Week of Color", but given the circumstances we are "Welcoming you to a new Online Color and Imaging Conference Edition"; hopefully, we can overcome this next year.

For this special edition we have tried to set a program in view of maximizing live interaction between participants, which was a complex problem for our world-wide community. We ended up with a conference version where a CIC day is split into two parts. While for those in California a CIC day has early morning and afternoon sessions, those in Asia will join late at night and early in the morning. And Europeans will attend afternoon and late-night sessions. Thankfully, attendants will be able to view the recordings of any talks they miss. All sessions present generic titles since technical chairs strongly tried to fit all presenters in adequate time zones.

The 15 short courses that are part of the program, run the two weeks prior to the program to allow everyone the ability to participate with less effort.

The Technical program presents similar numbers to previous years, with 30 oral talks, 29 interactive presentations, and 3 excellent keynotes:

- Colour Appearance and Spatio-chromatic Vision from Sophie Wuerger (University of Liverpool, UK)
- Why are there Colors in the Ocean? from Derya Akkaynak (Florida Atlantic University, US)
- Rethinking Color Measurement from Ayan Chakrabarti (Washington State University in St. Louis, US)

The week concludes with four Workshops on Skin Characterisation, Color in Arts, Future of Color Research, and VR/AR/MR related topics. In this case the schedule tried to fit the best time zones for the majority of participants in each specific workshop.

Looking forward we can adapt our daily life with this schedule and we can see each other via online tools. On the positive side, we can always think that this year we have saved some CO_2 emissions.

—CIC28 General Chair Maria Vanrell

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CIC28
ONLINE

SHORT COURSES

SC01 Color and Imaging
Instructor: Gaurav Sharma, University of Rochester

SC02 Advanced Colorimetry and Color Appearance
Instructor: Gaurav Sharma, University of Rochester

SC03 Camera Color Characterization: Theory and Practice
Instructors: Dietmar Wueller, Image Engineering GmbH & Co. KG and Eric Walowit, consultant

SC04 Fundamentals of Spectral Measurements for Color Science
Instructor: David Wyble, Avian Rochester, LLC

SC05 The Art of Making Better Pixels: High Dynamic Range Display Concepts and Technologies
Instructor: Timo Kunkel, Dolby Laboratories, LLC

SC06 Color and the Camera Imaging Pipeline
Instructor: Michael Brown, York University

SC07 Fundamentals of Psychophysics
Instructor: James A. Ferwerda, Rochester Institute of Technology

SC08 Using the New Colour Management Technology, iccMAX: Architecture and Practical Applications
Instructor: Philip Green, NTNU

SC09 Characterizing Surface Appearance
Instructor: James A. Ferwerda, Rochester Institute of Technology

SC10 Solving Color Problems using Vector Space Arithmetic
Instructor: Michael Vrhel, Artifex Software, Inc.

SC11 Color Essentials in LED Lighting Systems
Instructor: Michael Murdoch, Rochester Institute of Technology

SC12 Color Imaging Challenges with Compact Camera Optics
Instructor: Kevin Matherson, Microsoft Corporation

SC13 Spatial Color Perception and Image Processing
Instructor: Edoardo Provenzi, Université de Bordeaux

SC14 High Dynamic Range Imaging: Improvements and Limits after more than 20 Years of Research
Instructors: Alessandro Rizzi, Università Degli Studi di Milano and John McCann, McCann Imaging

SC15 Individual Differences in Color Matching and Appearance
Instructor: Mark Fairchild, Rochester Institute of Technology

EXHIBITOR

Image Engineering

For more than 25 years, Image Engineering has been testing the quality and performance of digital cameras.

They provide the necessary test equipment and also offer camera tests as a service. The standard test chart-based color reproduction tests are available throughout their portfolio from charts to evaluation software.

Since the late 90s, the company has also been providing more advanced approaches for camera color characterization. The development of devices such as camSPECS has made the measurement of the spectral response extremely simple and fast. In combination with an in-situ measured spectral database of natural objects and the utilization of CIECAM 16, an extremely high-quality level for color correction can be achieved and is supported by the software. This color correction can be performed in a test lab as well as on the production line for every single camera.

Last but not least, a lot of Image Engineering products have a built-in spectrally tunable light source that not only permits you to determine the spectral response of a camera but also allows illumination of objects with a selectable spectral distribution. Never before has the simulation of a standard light source such as A or D50 been more accurate and simple.

Visit them live via their booth Monday: 9:00 – 10:00 and 20:10 – 20:40; and Tuesday: 20:10 – 20:40

COOPERATING SOCIETIES

Comité de Color
European Optical Society (EOS)
The Finnish Color Association
Forum Farge
The French Color Imaging Group
German Society of Color Science and Application (DfwG)
GI Fachbereich Graphische Datenverarbeitung
Gruppo del Colore-Associazione Italiana Colore
Imaging Society of Japan (ISJ)
IOP Printing and Graphics Science Group
Inter-Society Color Council (ISCC)
NOBIM (Norwegian Association for Image Processing and Pattern Recognition)
Swedish Colour Centre Foundation
The Colour Group (Great Britain)
The Royal Photographic Society of Great Britain/ Imaging Science Group

TECHNICAL PROGRAM: SCHEDULE AND ABSTRACTS

DAY 1
MONDAY 16 NOVEMBER / TUESDAY 17 NOVEMBER

WELCOME AND OPENING KEYNOTE

Session Chair: Maria Vanrell, CVC - Universitat Autònoma de Barcelona (Spain)
16 NOV: 10:00 – 11:05 (NEW YORK) / 16:00 – 17:05 (PARIS)
17 NOV: 00:00 – 01:05 (TOKYO)

Welcome Remarks
Sessions Moderator: Maria Vanrell, CVC - Universitat Autònoma de Barcelona (Spain)

Colour Appearance and Spatio-chromatic Vision, *Sophie Wuerger, University of Liverpool (UK)*
The response of the human visual system depends on a multitude of image features, such as the wavelength (color) of the visual stimulus and its spatial frequency content. This talk reviews current models of color appearance, in particular unique hues as a tool to measure appearance and its potential applications. It then discusses how color is always associated with a spatial component, and how the chromatic and spatial information is encoded simultaneously, most likely in the same neurones. A review of experimental evidence on spatio-chromatic processing consistent with this idea is presented, and recent experiments on spatio-chromatic contrast sensitivity assessed on HDR displays is also discussed.

Exhibitor 2-minute Preview
Image Engineering: Visit them live via their booth Monday: 9:00 – 10:00 and 20:10 – 20:40; and Tuesday: 20:10 – 20:40

16 Nov: 11:05 – 11:30 (New York) / 17:05 – 17:30 (Paris)
17 Nov: 01:05 – 01:30 (Tokyo)
SESSION BREAK
Join the keynote speaker and other attendees in the CIC28 Discord Keynotes and Speakers channel.

COLOR VISION AND PERCEPTION SESSION I

Session Chair: Anya Hurlbert, Newcastle University (UK)
16 NOV: 11:30 – 12:10 (NEW YORK) / 17:30 – 18:10 (PARIS)
17 NOV: 01:30 – 02:10 (TOKYO)

11:30 (New York) / 17:30 (Paris)
01:30 (Tokyo)
CIC28 BEST PAPER: Practical Color Contrast Sensitivity Functions for Luminance Levels up to 10000 cd/m², *Rafal Mantiuk[1], Minjung Kim[1], Maliha Ashraf[2], Qiang Xu[3], Ming Ronnier Luo[3], Jasna Martinovic[4], and Sophie Wuerger[2]; [1]University of Cambridge (UK), [2]University of Liverpool (UK), [3]Zhejiang University (China), and [4]University of Edinburgh (UK)* . . . **1**
We model color contrast sensitivity for Gabor patches as a function of spatial frequency, luminance and chromacity of the background, modulation direction in the color space and stimulus size. To fit the model parameters, we combine the data from five independent datasets, which let us make predictions for background luminance levels between 0.0002 cd/m² and 10 000 cd/m², and for spatial frequencies between 0.06 cpd and 32 cpd. The data are well-explained by two models: a model that encodes cone contrast and a model that encodes postreceptoral, opponent-color contrast. Our intention is to create practical models, which can well explain the detection performance for natural viewing in a wide range of conditions. As our models are fitted to the data spanning very large range of luminance, they can find applications in modeling visual performance for high dynamic range and augmented reality displays.

11:50 (New York) / 17:50 (Paris)
01:50 (Tokyo)
Observer Metamerism: Why do [mis]Matches of Neutral Appear Pinkish or Greenish? *Yongmin Park[1,2], Michael Murdoch[1], and Mark Fairchild[1]; [1]Rochester Institute of Technology (US) and [2]LG Display (South Korea)* . . . **7**
White has been continuously considered as an essential color in numerous color applications. In particular, setting or tuning a reference white point is a key procedure in both camera and display applications. Various studies on observer metamerism pointed out that noticeable color disagreements between observers mainly appear in neutral colors. Thus, it is vital to understand how observer metamers of white (or neutral) appear in different colors by different observers. Most observers who participated in a visual demonstration reported that white observer metamers appear pinkish or greenish but not yellowish or bluish. In this paper, this intriguing question, "Why observer metamers of white are usually pinkish or greenish?", is addressed based on simulations. Besides, it is also analyzed that which physiological factors play an essential role in this phenomenon and whether it is possible for humans to perceive yellowish or bluish observer metamers of white.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS I FOLLOWED BY INTERACTIVE SESSION I AND BREAK

Session Chair: Alejandro Párraga, Universitat Autònoma de Barcelona (Spain)
16 NOV: 12:10 – 13:00 (NEW YORK) / 18:10 – 19:00 (PARIS)
17 NOV: 02:10 – 03:00 (TOKYO)
Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

Effect of Peak Luminance on Perceptual Color Gamut Volume, *Fu Jiang and Mark Fairchild, Rochester Institute of Technology (US), and Kenichiro Masaoka, NHK Science and Technology Research Laboratories (Japan)* . . . **13**
In this paper, two psychophysical experiments were conducted to explore the effect of peak luminance on the perceptual color gamut volume. The two experiments were designed with two different image data rendering methods: clipping the peak luminance and scaling the image luminance to display's peak luminance capability. The perceptual color gamut volume showed a close linear relationship to the log scale of peak luminance. The results were found not consistent with the computational 3D color appearance gamut volume from previous work. The difference was suspected to be caused by the different perspectives between the computational 3D color appearance gamut volume and the experimental color gamut volume/perceptual color gamut volume.

Quality assessment is performed through the use of variety of quality attributes. It is crucial to identify relevant attributes for quality assessment. We focus on 2.5D print quality assessment and its quality attributes. An experiment with observers showed the most frequently used attributes to judge quality of 2.5D prints with and without reference images. Colour, sharpness, elevation, lightness, and naturalness are the top five the most frequently used attributes for both with and without reference cases. We observed that content, previous experience and knowledge, and aesthetic appearance may impact quality judgement.

Previous research has shown the perceptual importance of facial colour appearance and how it contributes to perceived facial attractiveness, yet facial-colour perception may vary with different ethnic groups. This research was designed to explore the cross-cultural effects of the facial skin colour on perceived attractiveness between Chinese and Caucasian observers. 80 images of real human faces were used for facial attractiveness assessment by the two groups of observers using the categorical judgment method. The results showed overall similar preference but fine-scale differences in the perception of their own-ethnic facial images and other-ethnic facial images. Both groups of observers tended to use different criteria when judging the facial colour of different ethnic groups. Our findings show the aesthetic difference of different cultures in perceptions and underline the important role of ethnic differences with respect to skin tone preference.

The appearance mode of an object, whether it appears self-luminous or reflective, depends on its luminance and its surrounding. This research aims to verify whether the appearance mode of a spherical lamp ("on" / "off") can be used to predict room brightness and whether it is influenced by the presentation medium: real 3D scenes (R-3D), rendered virtual 3D scenes (VR-3D) presented on a head-mounted-display (HMD) and 2D scenes presented on a regular display (D-2D). Twenty observers evaluated the lamp's appearance mode when presented in different luminance values and rated the apparent room brightness of the scene under four viewing conditions: R-3D and D-2D with warm-white scene lighting, and D-2D and VR-3D with cool-white scene lighting. Border luminance, defined as the luminance corresponding to a 50-50 chance of perceiving a lamp as switched on, showed large observer variability, which might originate from the diversity of the observers' understanding of the lamp material and their strategy to judge the appearance mode. Respectively, border luminance and room brightness were significantly lower and significantly higher for the virtual reality scene than for the other conditions. However, no evidence was found that the appearance mode of a spherical lamp can relevantly predict room brightness.

Over the years, many CATs (chromatic adaptation transform), typically based on the von Kries coefficient rule, have been developed to predict the corresponding colors under different illuminants. However, these CATs were derived for uniform stimuli surrounded by a uniform adapting field. To investigate the adaptation state under spatially complex illumination, an achromatic matching experiment was conducted under dual lighting conditions with three color pairs and two transition types. It has been found that the transition type has an impact on both the equivalent chromaticity and degree of adaptation. These results can help build a comprehensive von Kries based CAT model, with considering the spatial complexity of illumination.

COLOR VISION AND PERCEPTION SESSION II

Session Chair: Anya Hurlbert, Newcastle University (UK)

16 NOV: 13:00 – 14:10 (NEW YORK) / 19:00 – 20:10 (PARIS)
17 NOV: 03:00 – 04:10 (TOKYO)

13:00 (New York) / 19:00 (Paris)
03:00 (Tokyo)

Banding is a type of quantisation artefact that appears when a low-texture region of an image is coded with insufficient bitdepth. Banding artefacts are well-studied for standard dynamic range (SDR), but are not well-understood for high dynamic range (HDR). To address this issue, we conducted a psychophysical experiment to characterise how well human observers see banding artefacts across a wide range of luminances (0.1 cd/m^2–10,000 cd/m^2). The stimuli were gradients modulated along three colour directions: black-white, red-green, and yellow-violet. The visibility threshold for banding artefacts was the highest at 0.1 cd/m^2, decreased with increasing luminance up to 100 cd/m^2, then remained at the same level up to 10,000 cd/m^2. We used the results to develop and validate a model of banding artefact detection. The model relies on the contrast sensitivity function (CSF) of the visual system, and hence, predicts the visibility of banding artefacts in a perceptually accurate way.

13:20 (New York) / 19:20 (Paris)
03:20 (Tokyo)

We learn the color of objects and scenes through our experience in everyday life. The colors of things that we see more frequently are defined as memory colors. These help us communicate, identify objects, detect crop ripeness or disease, evaluate the weather, and recognize emotions. Color quality has become a priority for the smartphone and camera industry. Color quality assessment (CQA) provides insight into user preference and can be put to use to improve cameras and display pipelines. The memory color of important content like human skin, food, etc. drives perceived color quality. Understanding memory color preference is critical to understanding perceived color quality. In this study, grass, sky, beach sand, green pepper, and skin were used to perform memory color assessment. Observers were asked to adjust patches with four different textures, including computed textures and real image content, according to their memory. The results show that observers adjust the image patch most consistently. In cases where the artificially generated textures closely resembled the real image content, particularly for the sky stimulus, which resembled a flat color patch, participants were able to adjust each sample more consistently to their memory color. To understand the relation between memory color and the color quality preference for camera images, a second experiment was performed. A paired comparison for familiar objects was performed with

five different color quality images per object. Two of these five images were rendered from the results of the memory color assessment experiment. Additional images included were the three most preferred color quality images from a rank order CQA. This experiment was performed by naïve observers and a validation experiment was also performed by Munsell Color Science Laboratory observers. The results for color image rendering preference for each memory image content vary. The results show that for most of the colors, people prefer the top three camera color quality images used from the rank order CQA. For grass, however, the color quality preference is highest for one of the memory color assessment results. In this experiment, images rendered to reflect memory color do not match observer preference.

13:40 (New York) / 19:40 (Paris)
03:40 (Tokyo)
Spatio-chromatic Contrast Sensitivity across the Lifespan: Interactions between Age and Light Level in High Dynamic Range, *Maliha Ashraf[1], Sophie Wuerger[1], Minjung Kim[2], Jasna Martinovic[3], and Rafal Mantiuk[2]; [1]University of Liverpool, [2]University of Cambridge, and [3]University of Edinburgh (UK)* **65**
We investigated spatio-chromatic contrast sensitivity in both younger and older color-normal observers. We tested how the adapting light level affected the contrast sensitivity and whether there was a differential age-related change in sensitivity. Contrast sensitivity was measured along three directions in colour space (achromatic, red-green, yellowish-violet), at background luminance levels from 0.02 to 2000 cd/m^2, and different stimuli sizes using 4AFC method on a high dynamic range display. 20 observers with a mean age of 33 y.o.a. and 20 older observers with mean age of 65 participated in the study. Within each session, observers were fully adapted to the fixed background luminance. Our main findings are: (1) Contrast sensitivity increases with background luminance up to around 200 cd/m^2, then either declines in case of achromatic contrast sensitivity, or remains constant in case of chromatic contrast sensitivity; (2) The sensitivity of the younger age group is higher than that for the older age group by 0.3 log units on average. Only for the achromatic contrast sensitivity, the old age group shows a relatively larger decline in sensitivity for medium to high spatial frequencies at high photopic light levels; (3) Peak frequency, peak sensitivity and cut-off frequency of contrast sensitivity functions show de-creasing trends with age and the rate of this decrease is dependent on mean luminance. The data is being modeled to predict contrast sensitivity as a function of age, luminance level, spatial frequency, and stimulus size.

14:00 – 14:10 (New York) / 20:00 – 20:10 (Paris)
04:00 – 04:10 (Tokyo)
Concluding Remarks
Sessions Moderator: Maria Vanrell, CVC - Universitat Autònoma de Barcelona (Spain)

Break in program to accommodate time zones

COLOR VISION AND PERCEPTION SESSION III

Session Chair: Takahiko Horiuchi, Chiba University (Japan)
16 NOV: 18:00 – 18:50 (NEW YORK)
17 NOV: 00:00 – 00:50 (PARIS) / 08:00 – 08:50 (TOKYO)

Welcome Remarks
Sessions Moderator: Michael J. Murdoch, Rochester Institute of Technology (US)

18:10 (New York)
00:10 (Paris) / 08:10 (Tokyo)
JIST-First: Glossiness-aware Image Coding in JPEG Framework, *Midori Tanaka, Tomoyuki Takanashi, and Takahiko Horiuchi, Chiba University (Japan)* **70**
In images, the representation of glossiness, translucency, and roughness of material objects (Shitsukan) is essential for realistic image reproduction. To date, image coding has been developed considering various indices of the quality of the encoded image, for example, the peak signal-to-noise ratio. Consequently, image coding methods that preserve subjective impressions of qualities such as Shitsukan have not been studied. In this study, the authors focus on the property of glossiness and propose a method of glossiness-aware image coding. Their purpose is to develop an encoding algorithm that produces images that can be decoded by standard JPEG decoders, which are commonly used worldwide. The proposed method consists of three procedures: block classification, glossiness enhancement, and non-glossiness information reduction. In block classification, the types of glossiness in a target image are classified using block units. In glossiness enhancement, the glossiness in each type of block is emphasized to reduce the amount of degradation of glossiness during JPEG encoding. The third procedure, non-glossiness information reduction, further compresses the information while maintaining the glossiness by reducing the information in each block that does not represent the glossiness in the image. To test the effectiveness of the proposed method, the authors conducted a subjective evaluation experiment using paired comparison of images coded by the proposed method and JPEG images with the same data size. The glossiness was found to be better preserved in images coded by the proposed method than in the JPEG images.

18:30 (New York)
00:30 (Paris) / 08:30 (Tokyo)
JIST-First: Texture-aware Error Diffusion Algorithm for Multi-level Digital Halftoning, *Donghui Li, Takuma Kiyotomo, Midori Tanaka, and Takahiko Horiuchi, Chiba University, and Kaku Shigeta, Think Laboratory Co., Ltd. (Japan)* **85**
Digital halftoning is a technique for converting a continuous-tone image into a quantized image to reproduce it on a digital printing device. Error diffusion (ED) is an algorithm that has proven to be effective for the halftoning process, and it has been widely applied to digital printing tasks. However, in images reproduced using conventional ED algorithms based on the signal processing theory, the texture of objects is often lost. In this study, we propose a texture-aware ED algorithm for multi-level digital halftoning. First, we generate multiple mapped images with different brightness levels through nonlinear transformation. For each mapped image, we adopt a texture-aware binary error diffusion method to obtain multiple halftone images. Finally, we generate a multi-level halftone image from the multiple halftone images. We test the algorithm on an actual printer, compare the results with those of the current raster image processor software and classical ED algorithms, and observe that our algorithm outputs better results.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS II FOLLOWED BY INTERACTIVE SESSION II AND BREAK

Session Chair: Susan Farnand, Rochester Institute of Technology (US)

16 NOV: 18:50 – 19:40 (NEW YORK) /
17 NOV: 00:50 – 01:40 (PARIS) / 08:50 – 09:40 (TOKYO)

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

A large-scale experiment was conducted to investigate facial image quality on mobile phones. There were 8 original facial images from 4 skin tone types, each included a male and a female image. Each image was captured at 6500K and they were rendered to have 5 CCT (correlated colour temperature) and 5 Duv (the shifts away from the Blackbody locus) levels via CAT02 chromatic adaptation transform to simulate the effect of the images captured under 25 different lighting conditions. Each image was assessed under 9 ambient lighting conditions (including one dark condition) by 90 observers from 3 ethnic groups (Caucasian, Chinese, and South Asian), each 30 observers. Preferred facial skin tone ellipse was established by maximizing the correlation coefficient between the model predicted probability and the preference percentage from the visual results. Four types of preferred skin tones had small differences in hue angle and chroma, but concentrated into a small colour region, about [24.7, 46.1°] for Cab* and hab values respectively. All ethnic group preferred images taken under illuminants having high CCT (6500-8000 K). It was also found that the chroma of the preferred skin tones will slightly increase as the ambient lighting CCT decrease.

High dynamic range (HDR) imaging has greater contrast reproduction capability than standard imaging techniques. It can achieve natural and pleasing appearance in terms of image quality. A tone mapping model (TMOz) is developed based on the center-surround properties of the mammalian ganglion cells of the human visual system for feature enhancement. The contrast of the HDR image is mapped adaptively to an SDR display range using a global method followed by contrast enhancement in local regions. A psychophysical experiment was conducted to refine the model for adaptivity of the contrast mapping function. Finally, the performance of the TMOz was evaluated using CIELAB (2:1) formula together with high quality reference images. The results showed that TMOz outperformed the other tone mapping operators (TMOs).

To investigate individual property of internal color representation of congenital red-green color-deficient observers (CDOs) and color-normal observers (CNOs) precisely, difference scaling experiment using pairs of primary colors was carried out for protans, deutans, and normal trichromats, and the results were analyzed using multidimensional Scaling (MDS). MDS configuration of CNOs showed circular shape similar to hue circle, whereas that of CNO showed large individual differences from circular to U-shape. Distortion index, DI, is proposed to express the shape variation of MDS configuration. All color chips were plotted in the color vision space, (L, r/g, y/b), and the MDS using a nonlinear conversion from the distance in the color vision space to perceptual difference scaling was successful to obtain U-shape configuration that reflects internal color representation of CDOs.

Producing preferred skin colours is vital for the digital images on mobile phone manufacturers. Previous studies investigated the skin colours only in chromatic plane excluding lightness. A psychophysical experiment was conducted to determine preferred skin colour centres for different skin colour types on mobile displays in a darkened room. Ten facial images were selected for the experiment to cover different skin colour types (Caucasian, Oriental, South Asian and African). A set of 49 predetermined colour centres uniformly sampled within the skin colour ellipsoid in CIELAB colour space was used to morph skin colours of test images. Thirty observers from each of the 3 ethnic groups (Caucasian, Oriental, and South Asian) participated in the experiment. The preferred skin colour centre and region in the form of ellipsoid for each skin group were reported. It was found that the preferred colour centres from different skin colour types were very similar except their lightness as expected, and were also quite similar between the observers from different ethnic groups.

Animated emoji in augmented reality (AR) enables users to create a humanoid version of themselves that mimics their facial expressions dynamically. In this study, we aim to explore how people perceive facial skin color in digital portrait in comparison with humanoid emoji in AR. We tried to identify the skin color representative regions and to estimate the color difference between the two contexts. We conducted a user study comprised of three tasks with 20 graduate students majoring in design and employed 24 portrait images in four skin tone categories. Through the user study, we first figured out that forehead and cheek regions, and particularly the linking band between eye and lip, were often considered as the representative region of facial skin color. Second, we observed skin colors become lighter in general, except dark tone. Furthermore, concerning the vividness, all four skin tone types became paler in humanoid emoji. Diverse ethnicities and contexts are expected in the future to provide a more robust and reliable analysis of the perception of skin color.

COLOR VISION AND PERCEPTION SESSION IV

Session Chair: Takahiko Horiuchi, Chiba University (Japan)

16 NOV: 19:40 – 20:50 (NEW YORK)
17 NOV: 01:40 – 02:50 (PARIS) / 09:40 – 10:50 (TOKYO)

19:40 (New York)
01:40 (Paris) / 09:40 (Tokyo)

Regular observation and recording of the changes in body appearance are essential for the process of the treatment of plastic surgery and dermatology, especially aesthetic surgery. Usually, physicians treat patients

with medical interviews, pictures of the patient's faces before and after their treatment, anatomical data that including size, location, and color of the affected skin. However, it is difficult to capture the affected area under the same conditions every time because the captured range varies depending on the imaging angle and distance. There is a need to record three-dimensional shape of face parts such as cheek, nose, eye, and chin. Therefore, in this study, the face shape and the skin color were measured using the infrared depth camera and the RGB camera built in the smartphone three-dimensionally. We measured before and after modulating the shape and color of the face, and then, the change in volume and the change in skin pigment of skin color was calculated and visualized. This method makes it possible to analyze the skin shape and color independently of the viewing angle and the illumination direction. In this study, the depth sensor built in the smartphone showed the potential to monitor changes in facial shape and skin color. In the future, it is expected to contribute to the development of telemedicine, in which the patient measures their face at home and gets medical treatment consultation remotely.

20:00 (New York)
02:00 (Paris) / 10:00 (Tokyo)
Are Spatial Chromatic Contrast Sensitivity Band-pass or Low-pass Functions?, *Qiang Xu[1], Stephen Westland[2], Marcel Lucassen[3], Dragan Sekulovski[3], Sophie Wuerger[4], Rafal Mantiuk[5], and Ming Ronnier Luo[1,2]; [1]Zhejiang University (China), [2]University of Leeds (UK), [3]Philips Lighting Research (the Netherlands), [4]University of Liverpool (UK), and [5]University of Cambridge (UK)* **125**
The goal of this research is to generate high quality chromatic Contrast Sensitivity Function (CSF) over a wide range of spatial frequencies from 0.06 to 3.84 cycles per degree (cpd) surrounding 5 CIE proposed colour centres (white, red, yellow, green and blue) to study colour difference. At each centre, 6 colour directions at each of 7 frequencies were sampled, from 0.06 to 3.84 cycles per degree (cpd) corresponding to the number of cycles: from 2.3 to 144.4 respectively. A threshold method based on forced-choice stair-case was adopted to investigate the just noticeable (threshold) colour difference. The results revealed that the chromatic CSF under the present experimental conditions having many lower spatial frequencies covering five colour centres to be band pass, whereas previous results indicated it was low pass. However, this could be caused by the present experimental conditions such as fixed-size stimuli and constant luminance. The new chromatic CSF for R-G and Y-B channels were also developed.

20:20 (New York)
02:20 (Paris) / 10:20 (Tokyo)
Investigating Effects of Visual and Auditory Adaptation on Metallic Material Appearance, *Takumi Nakamura, Daichi Yagi, Kuangzhe Xu, Toshihiko Matsuka, and Keita Hirai, Chiba University (Japan)* **130**
In this paper, we investigated the effects of visual and auditory adaptation on material appearance. The target in this study was metallic perception. First, participants evaluated CG images using sounds and other images. In the experiment, we prepared metallic stimulus under various adaptation conditions with different combinations of metal image, non-metal image, metal sound, and non-metal sound stimuli. After these adaptations, the participants answered "metal" or "non-metal" after viewing a displayed reference image. The reference images were generated by interpolating metal and non-metal images. Next, we analyzed the results and clarified the effects of visual, auditory, and audiovisual adaptations on the metallic perception. For analyzing results, we used a logistic regression analysis based on Bayesian statistics. From the analysis results, we found visual and auditory adaptation effects. On the other hand, we did not find the cross-modal effects of audiovisual adaptation. Finally, we created a model of the linear sum of the visual and audio adaptation effects on metallic material appearance.

20:40 – 20:50 (New York)
02:40 – 02:50 (Paris) / 10:40 – 10:50 (Tokyo)
Concluding Remarks
Sessions Moderator: Michael J. Murdoch, Rochester Institute of Technology (US)

DAY 2
TUESDAY 17 NOVEMBER / WEDNESDAY 18 NOVEMBER

TUESDAY KEYNOTE

Session Chair: Peter Morovic, HP Inc. (Spain)
17 NOV: 10:00 – 11:00 (NEW YORK) / 16:00 – 17:00 (PARIS)
18 NOV: 00:00 – 01:00 (TOKYO)

Welcome Remarks
Sessions Moderator: Peter Morovic, HP Inc. (Spain)

Why are there Colors in the Ocean?, *Derya Akkaynak, Florida Atlantic University, Harbor Branch Oceanographic Institution (US)*
The color of ocean water provides us tremendous insights regarding the properties of the particles in it. For example using satellites that sense ocean color, we are able to monitor worldwide concentration of phytoplankton—tiny organisms in the water column that produce food for everything else in the ocean to eat. That ocean water has color, however, is precisely what is holding us back from unveiling the colors of everything else, i.e., the colors of the ocean flora, fauna, and the unique habitats that host them. Why does anything in the ocean have color, if that color is to be masked by the color of the water? What would we learn if we could survey the true colors of everything in the ocean?

17 Nov: 11:00 – 11:30 (New York) / 17:00 – 17:30 (Paris) /
18 Nov: 01:00 – 01:30 (Tokyo)
SESSION BREAK
Join the keynote speaker and other attendees in the CIC28 Discord Keynotes and Speakers channel.

COMPUTATIONAL COLOR SESSION I

Session Chair: Ingeborg Tastl, HP Inc. (US)
17 NOV: 11:30 – 12:10 (NEW YORK) / 17:30 – 18:10 (PARIS)
18 NOV: 01:30 – 02:10 (TOKYO)

11:30 (New York) / 17:30 (Paris)
01:30 (Tokyo)
Interactive White Balancing for Camera-rendered Images, *Mahmoud Afifi and Michael Brown, York University (Canada)*. **136**
White balance (WB) is one of the first photo-finishing steps used to render a captured image to its final output. WB is applied to remove the color cast caused by the scene's illumination. Interactive photo-editing software allows users to manually select different regions in a photo as examples of the illumination for WB correction (e.g., clicking on achromatic objects). Such interactive editing is possible only with images saved in a RAW

image format. This is because RAW images have no photo rendering operations applied and photo-editing software is able to apply WB and other photo-finishing procedures to render the final image. Interactively editing WB in camera-rendered images is significantly more challenging. This is because the camera hardware has already applied WB to the image and subsequent nonlinear photo-processing routines. These nonlinear rendering operations make it difficult to change the WB post-capture. The goal of this paper is to allow interactive WB manipulation of camera-rendered images. The proposed method is an extension of our recent work that proposed a post-capture method for WB correction based on nonlinear color-mapping functions. Here, we introduce a new framework that links the nonlinear color-mapping functions directly to user-selected colors to enable interactive WB manipulation. This new framework is also more efficient in terms of memory and run-time (99% reduction in memory and 3× speed-up). Lastly, we describe how our framework can leverage a simple illumination estimation method (i.e., gray-world) to perform auto-WB correction that is on a par with the WB correction results in reference 6.

11:50 (New York) / 17:50 (Paris)
01:50 (Tokyo)

JIST-First: A Flying Gray Ball Multi-illuminant Image Dataset for Color Research, *Hoda Aghaei and Brian Funt, Simon Fraser University (Canada)* **142**

For research in the field of illumination estimation and color constancy, there is a need for ground-truth measurement of the illumination color at many locations within multi-illuminant scenes. A practical approach to obtaining such ground-truth illumination data is presented here. The proposed method involves using a drone to carry a gray ball of known percent surface spectral reflectance throughout a scene while photographing it frequently during the flight using a calibrated camera. The captured images are then post-processed. In the post-processing step, machine vision techniques are used to detect the gray ball within each frame. The camera RGB of light reflected from the gray ball provides a measure of the illumination color at that location. In total, the dataset contains 30 scenes with 100 illumination measurements on average per scene. The dataset is available for download free of charge.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS III FOLLOWED BY INTERACTIVE SESSION III AND BREAK

Session Chair: Mathieu Hebert, Université Jean Monnet de Saint Étienne (France)

17 NOV: 12:10 – 13:00 (NEW YORK) / 18:10 – 19:00 (PARIS)
18 NOV: 02:10 – 03:00 (TOKYO)

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

A Way to Calibrate a Colour Texture Feature, *Hermine Chatoux[1], Noel Richard[1], Hela Jebali[2], Francois Lecellier[1], and Christine Fernandez-Maloigne[1]; [1]XLIM Laboratory (France) and [2]University of Tunis El Manar (Tunisia)* **150**

Several colour descriptors are presented each year. The existing protocols to evaluate and compare these descriptors are restricted to the use of image databases without information about the spatio-chromatic content. In this article, we present a first answer to calibrate a colour texture descriptor. By calibration, we intend evaluate the capacity of the descriptor to discriminate the non-uniform aspect according to different scales of samples. In order to assess all the possibilities in term of spatial frequencies and colour content, we propose to use reference images based on a fractal vector colour model. Three texture features are compared from this protocol allowing to express the interest of the proposed calibration sequence.

Weibull Tone Mapping for Underwater Imagery, *Chloe Game[1], Michael Thompson[2], and Graham Finlayson[1]; [1]University of East Anglia and [2]Gardline Ltd. (UK)* **156**

Imagery is a preferred tool for environmental surveys within marine environments, particularly in deeper waters, as it is nondestructive compared to traditional sampling methods. However, underwater illumination effects limit its use by causing extremely varied and inconsistent image quality. Therefore, it is often necessary to pre-process images to improve visibility of image features and textures, and standardize their appearance. Tone mapping is a simple and effective technique to improve contrast and manipulate the brightness distributions of images. Ideally, such tone mapping would be automated, however we found that existing techniques are inferior when compared to custom manipulations by image annotators (biologists).

Our own work begins with the observation that these user defined tonal manipulations are quite variable, though on average, are fairly smooth, gentle waving operations. To predict user-defined tone maps we found it sufficed to approximate the brightness distributions of input and user adjusted images by Weibull distributions and then solve for the tone curve which matched these distributions from input to output. Experiments demonstrate that our Weibull Tone Mapping (WTM) method is strongly preferred over traditional automated tone mappers and weakly preferred over the users' own tonal adjustments.

BRDF Rendering by Interpolation of Optimised Model Parameters, *Tanzima Habib, Phil Green, and Peter Nussbaum, Norwegian University of Science and Technology (Norway)* **162**

In this paper, we discuss an interpolation method which can be used to create a look up table to map tristimulus values to BRDF parameters. For a given tristimulus value, we interpolate the XYZ lattice formed by eight primaries and secondaries that were printed and measured, and their corresponding optimised BRDF parameters. The BRDF parameters are obtained by careful optimisation of the Ward model and Cook Torrance model with the BRDF measurements of these primaries. The interpolated BRDF parameters of nine test samples from the same printed samples were then evaluated against the optimised BRDF parameters and their reference BRDF measurements. The results show that, this simple and efficient interpolation method produces consistent BRDF parameters that preserves the diffuse colour of the input sample.

On Filters Making an Imaging Sensor more Colorimetric, *Hans Jakob Rivertz, Norwegian University of Science and Technology (Norway)* . . **169**

It is well understood that the color values from a digital camera are functions of the camera's spectral sensitivities, the reflectances of the objects in the scene as well as illumination and any filter that is placed between the object and the sensor. It is vital to select the correct illumination to optimize a color reproduction pipeline. In practice, the choice of the illumination is limited to the spectra of available light sources.

In this paper, we optimize a camera's colorimetric performance by theoretically mounting a filter to the lens. An ideal spectrum of the filter is obtained using the Luther optimization condition. By using variational calculus we reduce the optimization problem to a system of nonlinear equations on a Lie group. We solve the system of equations by applying Newton's method on a Lie group with a left invariant Riemannian structure. As expected from the literature, our experiments show quadratic convergence.

A second approach is a redesign of the set-up. This redesign gives us a quadratic optimization problem that is easier to solve. Constraints to this optimization problem gives us control on the transparency of the filter.

Fake Video Detection Using Facial Color, *Hadas Shahar and Hagit Hel-Or, University of Haifa (Israel)* **175**
The field of image forgery is widely studied, and with the recent introduction of deep networks based image synthesis, detection of fake image sequences has increased the challenge. Specifically, detecting spoofing attacks is of grave importance. In this study we exploit the minute changes in facial color of human faces in videos to determine real from fake videos. Even when idle, human skin color changes with sub-dermal blood flow, these changes are enhanced under stress and emotion. We show that extracting facial color along a video sequence can serve as a feature for training deep neural networks to successfully determine fake vs real face sequences.

COMPUTATIONAL COLOR SESSION II

Session Chair: Ingeborg Tastl, HP, Inc. (US)

17 NOV: 13:00 – 14:10 (NEW YORK) / 19:00 – 20:10 (PARIS)
18 NOV: 03:00 – 04:10 (TOKYO)

13:00 (New York) / 19:00 (Paris)
03:00 (Tokyo)
Designing a Color Filter via Optimization of Vora-Value for Making a Camera more Colorimetric, *Yuteng Zhu and Graham Finlayson, University of East Anglia (UK)* **181**
Previous work has proposed to solve for a filter which, when placed in front of a camera, improves the colorimetric property by best satisfying the Luther condition. That is, the filtered spectral sensitivities of a camera—after a linear transform—are as close to the color matching functions of the human visual system as possible. By construction, the prior art solves for a filter for a given set of human visual sensitivities, e.g. the XYZ color matching functions or the cone response functions. However, depending on the target spectral sensitivity set, a different optimal filter is found.

In this paper, we set out a method to solve for a filter that works equally well for all possible target sensitivity sets of the human visual system. We observe that the cone fundamentals, the CIE XYZ color matching functions or any linear combination thereof, span the same vector space. Thus, we solve for a filter that makes the vector space spanned by the filtered camera sensitivities as similar as possible to the space spanned by human vision sensors. We argue that the Vora-Value is a suitable way to measure subspace similarity and we develop an optimization method for finding a filter that maximizes the Vora-Value measure.

Experiments demonstrate that our new optimization leads to the filtered camera sensitivities which have a significantly higher Vora-Value and improved colorimetric performance compared with antecedent methods.

13:20 (New York) / 19:20 (Paris)
03:20 (Tokyo)
Improved Camera Color Accuracy in the Presence of Noise with a Color Prefilter, *Michael Vrhel, Artifex Software (US)* **187**
It is possible to achieve improved color accuracy with a color camera by placing a color filter in front of the camera. Unfortunately, the color filter will block some of the light entering the camera, which will result in additional noise in the recorded data. This paper provides an initial investigation into finding an optimal solution to the filter design, in the presence of noise.

13:40 (New York) / 19:40 (Paris)
03:40 (Tokyo)
Improving Color Space Conversion for Camera-captured Images via Wide-gamut Metadata, *Hoang Le, Mahmoud Afifi, and Michael Brown, York University (Canada)* **193**
Color space conversion is the process of converting color values in an image from one color space to another. Color space conversion is challenging because different color spaces have different sized gamuts. For example, when converting an image encoded in a medium-sized color gamut (e.g., AdobeRGB or Display-P3) to a small color gamut (e.g., sRGB), color values may need to be compressed in a many-to-one manner (i.e., multiple colors in the source gamut will map to a single color in the target gamut). If we try to convert this sRGB-encoded image back to a wider gamut color encoding, it can be challenging to recover the original colors due to the color fidelity loss. We propose a method to address this problem by embedding wide-gamut metadata inside saved images captured by a camera. Our key insight is that in the camera hardware, a captured image is converted to an intermediate wide-gamut color space (i.e., ProPhoto) as part of the processing pipeline. This wide-gamut image representation is then saved to a display color space and saved in an image format such as JPEG or HEIC. Our method proposes to include a small sub-sampling of the color values from the ProPhoto image state in the camera to the final saved JPEG/HEIC image. We demonstrate that having this additional wide-gamut metadata available during color space conversion greatly assists in constructing a color mapping function to convert between color spaces. Our experiments show our metadata-assisted color mapping method provides a notable improvement (up to 60% in terms of ΔE) over conventional color space methods using perceptual rendering intent. In addition, we show how to extend our approach to perform adaptive color space conversion based spatially over the image for additional improvements.

14:00 – 14:10 (New York) / 20:00 – 20:10 (Paris)
04:00 – 04:10 (Tokyo)
Concluding Remarks
Sessions Moderator: Peter Morovic, HP Inc. (Spain)

Break in program to accommodate time zones

COMPUTATIONAL COLOR SESSION III

Session Chair: Pei Li Sun, National Taiwan University of Science and Technology (Taiwan)

17 NOV: 18:00 – 18:50 (NEW YORK)
18 NOV: 00:00 – 00:50 (PARIS) / 08:00 – 08:50 (TOKYO)

Welcome Remarks
Sessions Moderator: Jérémie Gerhardt, Faurecia IRYStec Inc. (Canada)

18:10 (New York)
00:10 (Paris) / 08:10 (Tokyo)
Camera ISP Modification to Enable Image De-rendering, *Abhijith Punnappurath and Michael Brown, Samsung Research, AI Center (Canada)* **199**
A camera's image signal processor (ISP) is dedicated hardware that performs a series of processing steps to render a captured raw sensor image to its final display-referred output suitable for viewing and sharing. It is often desirable to be able to revert—or de-render—the ISP-processed image back to the original raw sensor image. Undoing the ISP rendering, however, is not an easy task. This is because ISPs perform many nonlinear routines in the rendering pipeline that are difficult to invert. Moreover, modern cameras often apply scene-specific image processing, resulting in a wide range of possible ISP parameters. In this paper, we propose a

modification to the ISP that allows the ISP-rendered image to be reverted back to a raw image. Our approach works by appending a fixed-sampling of the raw sensor values to all captured images. The appended raw samples comprise no more than 8 rows of pixels in the full-sized image and represent a negligible overhead given that 12–16 MP sensors typically have 3000 rows of pixels or more. The appended pixels are rendered along with the captured image to the final output. From these rendered raw samples, a reverse mapping function can be computed to undo the ISP processing. We demonstrate that this method performs almost on par with competing state-of-the-art approaches for ISP de-rendering while offering a practical solution that is integrable to current camera ISP hardware.

18:30 (New York)
00:30 (Paris) / 08:30 (Tokyo)

Spectral Reflectance Estimation Using Projector with Unknown Spectral Power Distribution, *Hironori Hidaka, Yusuke Monno, and Masatoshi Okutomi, Tokyo Institute of Technology (Japan)* **205**

A lighting-based multispectral imaging system using an RGB camera and a projector is one of the most practical and low-cost systems to acquire multispectral observations for estimating the scene's spectral reflectance information. However, existing projector-based systems assume that the spectral power distribution (SPD) of each projector primary is known, which requires additional equipment such as a spectrometer to measure the SPD. In this paper, we present a method for jointly estimating the spectral reflectance and the SPD of each projector primary. In addition to adopting a common spectral reflectance basis model, we model the projector's SPD by a low-dimensional model using basis functions obtained by a newly collected projector's SPD database. Then, the spectral reflectances and the projector's SPDs are alternatively estimated based on the basis models. We experimentally show the performance of our joint estimation using a different number of projected illuminations and investigate the potential of the spectral reflectance estimation using a projector with unknown SPD.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS IV FOLLOWED BY INTERACTIVE SESSION IV AND BREAK

Session Chair: Erika Kanematsu, Nikon Corporation (Japan)

17 NOV: 18:50 – 19:40 (NEW YORK)
18 NOV: 00:50 – 01:40 (PARIS) / 08:50 – 09:40 (TOKYO)

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

Optimal Text-background Lightness Combination for Enhancing Visual Clarity Using a Head-up Display under Different Surround Conditions, *Hsin-Pou Huang[1], Minchen Wei[2], Hung-Chung Li[3], and Li-Chen Ou[4]; [1]Chihlee University of Technology (Taiwan), [2]The Hong Kong Polytechnic University (Hong Kong), [3]Academia Sinica (Taiwan), and [4]National Taiwan University of Science and Technology (Taiwan)* **210**

Head-up displays (HUDs) can be used under various surround conditions ranging from extremely dark to very bright environments such as daylight. Many head-up displays are designed to enhance visual clarity by adjusting the brightness of the display. However, few studies aim to investigate the impacts of the text-background lightness combination of a head-up display to the visibility as the lighting level of the driving condition changes dramatically. In the study, thirteen observers assess the visual clarity of 20 text background lightness combinations on a head-up display with paired comparisons method under a dark and a daylight surround (i.e., 15000 lx) conditions. As a result, the combination of white text with a black background and the black text with a white background presents the significant preference and the best visual clarity under the dark and the daylight surround conditions, respectively.

Inverse-scaled Lanczos Filtering for Image Sharpening, *Hiroaki Kotera, Kotera Imaging Laboratory (Japan)* **215**

The edge response in retinal image is the first step for human vision recognizing the outside world. A variety of receptive field models for describing the impulse response have been proposed. Which satisfies the uncertain principle? occupied the interest from a point of minimizing the product $(\Delta x)(\Delta \omega)$ both in spatial and spectral. Among the typical edge response models, finally Gabor function and 2nd. Gaussian Derivative GD2 remained as strong candidates. While famous D. Marr and R. Young support GD2, many vision researchers prefer Gabor. The retinal edge response model is used for image sharpening.

Different from the conventional image sharpening filters, this paper proposes a novel image sharpening filter by modifying the Lanczos resampling filter. The Lanczos filter is used for image scaling to resize digital images. Usually it works to interpolate the discrete sampled points like as a kind of smoothing filter not as sharpening. The Lanczos kernel is given by the product of sampling Sinc function and the scaled Sinc function. The scaled Sinc function expanded by the scale "s" plays a role of window function. The author noticed that the inverse scaling of Lanczos window can be used not for smoothing but for sharpening filter.

This paper demonstrates how the proposed model works effectively in comparison with Gabor and GD2.

Using Images of the Tongue for Diagnostic Assistance in Kampo Medicine, *Reimei Koike[1], Keiko Ogawa-Ochiai[2], Hongyang Li[2]; and Norimichi Tsumura[1]; [1]Chiba University and [2]Kanazawa University Hospital (Japan)* **221**

In this research, we propose a method to assess images of the tongue captured using a polarized light camera for diagnostic use in Kampo Medicine. The polarized light camera is used to simultaneously capture glossy and non-glossy images of the tongue. Data augmentation was performed by modulating the color and gloss, through which the number of images was increased from 11 to 275. A diagnostic assistance module was built to evaluate a given disease by learning a specialist's assessment of it along with feature values obtained from the captured image using a machine learning technique. The resulting mean absolute error of the assessment of five diseases was sufficiently small for it to be accurate.

Estimation Method of Fluorescent Donaldson Matrices based on Multispectral Imaging Data, *Shoji Tominaga, Norwegian University of Science and Technology (Norway) and Nagano University (Japan)* . . . **227**

This paper proposes a compact and reliable method to estimate the bispectral Donaldson matrices of fluorescent objects by using multispectral imaging data. We suppose that an image acquisition system allows multiple illuminant projections to the object surface and multiple response channels in the visible range. The Donaldson matrix is modeled as a two-dimensional array with the excitation range (350, 700 nm) and the reflection and emission ranges (400, 700 nm). The observation model is described using the spectral sensitivities of a camera and the spectral functions of reflectance, emission, and excitation. The problem of estimating the spectral functions is formulated as a least squares problem to minimize the residual error of the observations and the roughness of the spectral functions. An iterative algorithm is developed to obtain the optimal estimates of the whole spectral functions. The performance of the proposed method is examined in simulation experiments using multispectral imaging data in detail.

Characterization of Color Differences for Color Palette, *Jialu Wu[1], Jie Yang[2], Minchen Wei[1], Kaida Xiao[2], and Stephen Westland[2]; [1]The Hong Kong Polytechnic University (Hong Kong) and [2]University of Leeds (UK)* **232**

Various color difference metrics were developed for characterizing the perceived color difference between individual color patches. Color difference between palettes containing multiple color patches, however, is critically important in product design and computer graphics. This study aimed to investigate how the perceived color difference between a pair of color palettes containing more than a single color patch is affected by the order and number of color patches in the palette. Two reference color sets were generated and each set had four color palettes containing 1, 4, 9, and 16 color patches that were arranged as 1 × 1, 2 × 2, 3 × 3, and 4 × 4 patterns. Human observers scaled the color differences between a color palette of the reference set and a color palette that had revised colors, or revised orders, or a combination of revised colors and orders compared to the reference palette. The calculated color differences between the two palettes were derived using the Minimum Color Difference Model (MICDM) algorithm proposed in a recent work with different color difference metrics, including CIELAB, CMC, CIE94, and DE2000. It was found that the perceived color differences of pairs of individual color patches were significantly larger than those containing multiple patches, when the calculated color differences were the same. The color differences metrics, except for CIE94, had similar performance when characterizing perceived color differences between color palettes.

COMPUTATIONAL COLOR SESSION IV

Session Chair: Pei Li Sun, National Taiwan University of Science and Technology (Taiwan)

17 NOV: 19:40 – 20:50 (NEW YORK)
18 NOV: 01:40 – 02:50 (PARIS) / 09:40 – 10:50 (TOKYO)

19:40 (New York)
01:40 (Paris) / 09:40 (Tokyo)

Effect of Color Gamut and Luminance on Observer Metamerism in HDR Displays, *Yongmin Park[1,2] and Michael Murdoch[1]; [1]Rochester Institute of Technology (US) and [2]LG Display (South Korea)* **237**

Observer metamerism (OM) is one of the potential issues in HDR displays because of the required wide color gamuts and high peak luminance levels. A simulation was performed using hypothetical displays to investigate how OM in HDR displays would vary with changes in color gamuts and peak luminance levels. In this work, a robust metric, observer metamerism magnitude (OMM) is introduced, which quantifies the OM of paired displays, depending on the similarity in spectral bandwidth between them. Also, the effect of changes in peak luminance on OM was found to be small, increasing OMM by 7 ~ 8% when peak luminance doubles.

20:00 (New York)
02:00 (Paris) / 10:00 (Tokyo)

JPI-First: Using Gaussian Spectra to Derive a Hue-linear Color Space, *Luke Hellwig and Mark Fairchild, Rochester Institute of Technology (US)* **244**

A new color space, IGPGTG, was developed. IGPGTG uses the same structure as IPT, but while IPT was optimized to visual data on perceived hue, IGPGTG was optimized based on evidence linking the shape of light spectra to their perceived hues. The performance of IGPGTG on perceived hue data was compared to the performance of other established color spaces. Additionally, an experiment was run to directly compare the hue uniformity of IGPGTG to other color spaces, using Case V of Thurstone's Law of Comparative Judgement to generate hue uniformity scales. IGPGTG performed well in this experiment but poorly on the extant visual data. The mixed results indicate that it is possible to derive a moderately hue-uniform color space without visual data.

20:20 (New York)
02:20 (Paris) / 10:20 (Tokyo)

Von Kries 2020: Evolution of Degree of Chromatic Adaptation, *Mark Fairchild, Rochester Institute of Technology (US)* **252**

Recent data has shown that the process of chromatic adaptation might be asymmetrical, or irreversible, and that this effect might be more than simply a manifestation of the time course of adaptation. This paper introduces a simple modification of the von Kries chromatic adaptation transform, referred to as vK20 that can account for the asymmetry in chromatic adaptation through inclusion of previous adapting conditions. Also introduced is a new reference chromaticity (~15000K) for degree of adaptation that seems more physiologically plausible than the commonly used equal-energy (EE) illuminant or CIE illuminant D65.

20:40 – 20:50 (New York)
02:40 – 02:50 (Paris) / 10:40 – 10:50 (Tokyo)

Concluding Remarks

Sessions Moderator: Jérémie Gerhardt, Faurecia IRYStec Inc. (Canada)

CIC28 ONLINE

DAY 3
WEDNESDAY 18 NOVEMBER / THURSDAY 19 NOVEMBER

CLOSING KEYNOTE

Session Chair: Michael Brown, York University (Canada)

18 NOV: 10:00 – 11:00 (NEW YORK) / 16:00 – 17:00 (PARIS)
19 NOV: 00:00 – 01:00 (TOKYO)

Welcome Remarks

Rethinking Color Measurement, *Ayan Chakrabarti, Washington State University in St. Louis McKelvey School of Engineering (US)*

Most digital cameras in use today measure color through spatial multiplexing: interestingly, still relying on the Bayer pattern from the 1970s. In this talk, Chakrabarti describes new approaches to thinking about digital color sensors and reconstruction algorithms, borrowing ideas from those that have been successful in related computer vision algorithms. The talk begins by describing a sensor design and reconstruction method based on sparse color measurement, which draws inspiration from "interactive colorization" algorithms that are able to convert black and white images to color from a few color strokes as annotation. Then, Chakrabarti argues for a more data-driven way for jointly designing sensors and computational reconstruction algorithms. In this spirit, the talk explains an automated way to "learn" the right multiplexed color measurement strategy, by treating the color sensor as a "layer" in a neural network. Experimental results will show the benefits of both approaches, and interestingly, that the learning-based approach is able to automatically discover a sparse measurement strategy as being optimal. The talk ends with a discussion on how data-driven sensor design can be a useful tool when building cameras for applications beyond reconstruction.

18 Nov: 11:05 – 11:30 (New York) / 17:05 – 17:30 (Paris) /
19 Nov: 01:05 – 01:30 (Tokyo)
SESSION BREAK
Join the keynote speaker and other attendees in the CIC28 Discord Keynotes and Speakers channel.

COLOR APPLICATIONS SESSION I

Session Chair: Jon Hardeberg, Norwegian University of Science and Technology (Norway)

18 NOV: 11:30 – 12:10 (NEW YORK) / 17:30 – 18:10 (PARIS)
19 NOV: 01:30 – 02:10 (TOKYO)

11:30 (New York) / 17:30 (Paris)
01:30 (Tokyo)

Linear Spectral Estimate Refinement for Spectral Reconstruction from RGB, *Tarek Stiebel and Dorit Merhof, RWTH Aachen University (Germany)* **258**

Spectral signal recovery from RGB-images based on modern deep learning techniques demonstrated promising results in recent years and offers a feasible alternative to costly or otherwise more complex spectral imaging devices. The state-of-the-art deep learning is formed by approaches that learn a direct end-to end mapping from RGB to spectral images from given RGB and spectral image pairs. Any prior knowledge, most importantly a known spectral responsivity of the imaging device, is not taken into account by the vast majority of deep learning based methods. Although attempts have been made to include prior knowledge with respect to the camera response functions, it remains unclear how to do so in a robust and constructive way. In this work, we propose a hybrid processing method utilizing a handcrafted linear map to directly obtain a good estimate on the spectral signal. Deep learning is only used for a subsequent signal refinement. In contrast to previous work, our linear estimate on the spectral signal is not subject to any network optimization and relies on explicit knowledge on the camera response. It is finally demonstrated that the proposed hybrid processing strategy reduces spectral reconstruction errors.

11:50 (New York) / 17:50 (Paris)
01:50 (Tokyo)

Reconstructing Spectra from RGB Images by Relative Error Least-squares Regression, *Yi-Tun Lin and Graham Finlayson, University of East Anglia (UK)* **264**

Spectral reconstruction (SR) algorithms attempt to map RGB- to hyperspectral-images. Classically, simple pixel-based regression is used to solve for this SR mapping and more recently patch-based Deep Neural Networks (DNN) are considered (with a modest performance increment). For either method, the 'training' process typically minimizes a Mean-Squared-Error (MSE) loss. Curiously, in recent research, SR algorithms are evaluated and ranked based on a relative percentage error, so-called Mean-Relative-Absolute Error (MRAE), which behaves very differently from the MSE loss function. The most recent DNN approaches - perhaps unsurprisingly - directly optimize for this new MRAE error in training so as to match this new evaluation criteria. In this paper, we show how we can also reformulate pixel-based regression methods so that they too optimize a relative spectral error. Our Relative Error Least-Squares (RELS) approach minimizes an error that is similar to MRAE. Experiments demonstrate that regression models based on RELS deliver better spectral recovery, with up to a 10% increment in mean performance and a 20% improvement in worst-case performance depending on the method.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS V FOLLOWED BY INTERACTIVE SESSION V AND BREAK

Session Chair: Kaida Xiao, University of Leeds (UK)

18 NOV: 12:10 – 13:00 (NEW YORK) / 18:10 – 19:00 (PARIS)
19 NOV: 02:10 – 03:00 (TOKYO)

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

Simple Primary Colour Editing for Consumer Product Images, *Han Gong, University of East Anglia, and Luwen Yu and Stephen Westland, University of Leeds, (UK)* **270**

We present a simple primary colour editing method for consumer product images. We show that by using colour correction and colour blending, we can automate the pain-staking colour editing task and save time for consumer colour preference researchers. To improve the colour harmony between the primary colour and its complementary colours, our algorithm also tunes the other colours in the image. A preliminary experiment has shown some promising results compared with a state-of-the-art method and human editing.

This paper proposes a multi-spectral imaging system, developed using a commercial-grade camera, under two commonly used illumination. Rather than using conventional direct or diffuse light, the novelty of our method is to use a cross-polarized imaging system to eliminate glare and specular highlights. Two RGB images are captured under two different color temperature lighting conditions. An improved reflectance estimation method is developed to transform camera RGB under two illumination to spectral reflectance using a regulated model, combining the polynomial expansion of the camera signals with optimally selected feature. The method was tested using both a semi-gloss ColorChecker SG (140) and matte ColorChecker DC (240) chart. The results indicate that the proposed method significantly outperforms the traditional methods both in terms of spectra and colorimetric accuracy. This new multi-spectral imaging system is sufficiently precise to predict spectra properties and its performance within an acceptable range.

The frieze of the Palace of the stuccoes, dated between the 5th and 6th century BC, was a polychrome Maya relief discovered in the 1907 in Yucatán, Mexico. It was documented in watercolours and hand tinted photographs by Adela Breton. After years of exposure to the harsh environmental conditions of the Maya area, the colours and the stucco relief disappeared. The aim of the project is to develop a hybrid digital-analogue printing method for reconstructing the appearance of the original polychrome relief based on digitised hand-made records.

A description of the process to produce full colour images combining digital and photomechanical printing is provided. Using photopolymer plates, an intaglio printing process has been used to produce colour images, whilst inverse relief plates have been created based on height maps to transfer a positive embossing on paper when applying pressure on a printing press. The influence of physical parameters related to the appearance is studied. Reflectance Transformation Imaging was carried out to record the colour and surface shape of the prints. Measurements of gloss were made on relief inkjet prints and intaglio prints on paper to compare the outcomes of commercial 2.5D print and the method proposed here.

By modifying an analogue process with digital technology, it is possible to incorporate ancient materials to the printmaking process and therefore approach naturally the appearance of the original. On the other hand, incorporating imaging techniques and quality measurements enables to improve the quality in analogue printing techniques.

Traffic light (TL) classification is an important feature for automated driving, and it requires correct color separation of the TL signals captured using cameras. A key camera component for the color separation performance is the color filter array (CFA). For common automotive-specific CFAs, we have observed unsatisfactory performance for TL color separation, which indicates the need for an optimization. Based on typical scenarios for TL classification and a set of recorded TL signals, we evaluate the performance of common automotive CFAs. For a quantitative evaluation, we propose a suitable color distance metric. We also propose a method for optimization of the CFA and show that using this method, reference color separation performance can be achieved, trading in only a small amount of sensitivity.

In complex scenes, the light reflected by surfaces causes secondary illumination, which contributes significantly to the actual light in the space (the "light field"). Secondary illumination is dependent on the primary illumination, geometry, and materials of a space. Hence, primary illumination and secondary illumination can have non-identical spectral properties, and render object colors differently. Lighting technology and research predominantly relies on the color rendering properties of the illuminant. Little attention has been given to the impact of secondary illumination on the "effective color rendering" within light fields. Here we measure the primary and secondary illumination for a simple spatial geometry and demonstrate empirically their differential "effective color rendering" properties. We found that color distortions due to secondary illumination from chromatic furnishing materials led to systematic and significant color shifts, and major differences between the lamp-specified color rendition and temperature and the actual light-based "effective color rendering" and "effective color temperature". On the basis of these results we propose a methodological switch from assessing the color rendering and temperature of illuminants only to assessing the "effective color rendering and temperature" in context too.

COLOR APPLICATION SESSION II

Session Chair: Jon Hardeberg, Norwegian University of Science and Technology (Norway)

18 NOV: 13:00 – 14:10 (NEW YORK) / 19:00 – 20:10 (PARIS)
19 NOV: 03:00 – 04:10 (TOKYO)

13:00 (New York) / 19:00 (Paris)
03:00 (Tokyo)

The properties of prints are not fully determined by the materials they are composed of and the method that was used to compose them. These merely set limits to what a print's properties, such as its colors, sharpness, smoothness, color inconstancy and level of ink use, will be and it is the role of a printing system's imaging pipeline to select a particular combination. Conventionally such choices are implicit in how resources for a pipeline are built and can be improved with experience and trial an error. Performance can be improved though by optimizing for specific attributes, as was previously shown for color consistency, ink use and grain among others. A key constraint that remains here is that optimization is performed on the basis of sampling and search strategies, which have inherent limitations. This paper presents a direct, analytical approach to optimization that hinges on the insight that it can be performed in a convex space even when the properties involved in the optimization do not relate to each other in a convex way. The result both improves performance versus previous methods and does so in considerably less time.

13:20 (New York) / 19:20 (Paris)
03:20 (Tokyo)

Minimising Ambient Illumination via Ambient Subtraction: Smartphone Assessment of Jaundice in Liver Patients via Sclera Images, *Miranda Nixon-Hill, Felix Outlaw, Lindsay W. MacDonald, Rajeshwar Mookerjee, and Terence S. Leung, University College London (UK)* **307**

Using smartphone images to quantify color presents a noninvasive way to assess jaundice and other color-related biomarkers of the human body. Here we focus on assessing jaundice through accurate bilirubin measurement in adult liver patients, the first time optical imaging has been applied to this cohort. These patients can suffer from very high levels of bilirubin, indicating their severity of liver disease. A smartphone assessment technique for jaundice based around the color of the sclera (white of the eye) extracted from images is being developed, as smartphone imaging enables cheap, non-invasive and quantitative readings. Variations in ambient light cause large changes to recorded pixel values so must be accounted for to ensure that any changes detected are due to changes in jaundice level. Here we suggest the use of an ambient subtraction approach to minimise the effects of ambient light. Pairs of flash/ no-flash images are captured and the extracted values subtracted to yield data as though under a pure flash illumination. We present data demonstrating the technique with a group of healthy adult volunteers. We also present data from a patient study involving adults with liver disease. Images were captured and the bilirubin (jaundice) level predicted from these images before and after subtraction was compared to the ground truth value obtained via blood test. The linear correlation coefficient increased from 0.47 to 0.85 ($p<0.001$ in both cases) upon application of substraction, demonstrating the effectiveness of the technique.

13:40 (New York) / 19:40 (Paris)
03:40 (Tokyo)

Reflectance and Transmittance of Flowable Dental Resin Composite Predicted by the Two-flux Model: On the Importance of Analyzing the Effective Measurement Geometry, *Vincent Duveiller[1], Lou Gevaux[1], Raphaël Clerc[1], Jean-Pierre Salomon[2,3,4], and Mathieu Hebert[1]; [1]Universite de Lyon (France), [2]Universite de Lorraine (France), [3]Universite de Haute Alsace (France), and [4]Oregon Health and Science University (US).* . . . **313**

Flowable direct resin composite materials used in the dental domain are among materials that scatter light rather weakly, giving to millimeter-thick samples a certain translucent aspect. In order to predict the spectral reflectance and the color of such samples, the two-flux theory, i.e., Kubelka-Munk model (with Saunderson correction), remains the standard approach used in the dental domain, in spite of its known limitations when scattering is too weak. The present study, however, shows that a careful analysis of the light signal effectively measured on weakly scattering samples with instruments based, as usually recommended, on the d:8° measurement geometry, and a subsequent reevaluation of the parameters used in the Saunderson correction formulas with respect to the effective measurement geometry, can considerably improve the prediction accuracy of the model in both reflectance and transmittance modes, as confirmed by experiments carried out with samples of dental flowable resin composite material of different thicknesses. This broadens the applicability domain of the model, and might satisfy users preferring the simplicity of the two-flux model and the affordable equipment it needs to more relevant but more complex light scattering theories.

14:00 – 14:10 (New York) / 20:00 – 20:10 (Paris)
04:00 – 04:10 (Tokyo)

Closoing Remarks

CIC28 General Chair Maria Vanrell, CVC - Universitat Autònoma de Barcelona (Spain)

Break in program to accommodate time zones

COLOR APPLICATION SESSION III

Session Chair: Nicolas Bonnier, Apple, Inc. (US)

18 NOV: 18:00 – 18:50 (NEW YORK)
19 NOV: 00:00 – 00:50 (PARIS) / 08:10 – 08:50 (TOKYO)

Welcome Remarks

Sessions Moderator: Eric Walowit, independent consultant (US)

18:10 (New York)
00:10 (Paris) / 08:10 (Tokyo)

Estimation of Layered Ink Layout to Reproduce Desired Translucency of Skin in Inkjet 3D Printer Using Deep Neural Network Trained with Synthetic Simulated Data, *Kensuke Fukumoto[1], Kazuki Nagasawa[1], Wataru Arai[2], Kunio Hakkaku[2], Satoshi Kaneko[2], Keita Hirai[1], and Norimichi Tsumura[1]; [1]Chiba University and [2]Mimaki Engineering Co., Ltd., (Japan)* **321**

In this paper, we propose a method to estimate ink layer layout used as an input for 3D printer. This method makes it possible to reproduce a 3D printed patch that gives a desired translucency, which is represented as Line Spread Function (LSF) in this study. Deep neural networks of encoder decoder model is used for the estimation. In a previous research, it is reported that machine learning method is effective to formulate the complex relationship between the optical property such as LSF and the ink layer layout in 3D printer. However, it may be difficult to collect data large enough to train a neural network sufficiently. Especially, although 3D printer is getting more and more widespread, the printing process is still time consuming. Therefore, in this research, we prepare the training data, which is the correspondence between LSF and ink layer layout in 3D printer, by simulating it on a computer. MCML was used to perform the simulation. MCML is a method to simulate subsurface scattering of light for multi-layered media. Deep neural network was trained with the simulated data, and evaluated using a CG skin object. The result shows that our proposed method can estimate an appropriate ink layer layout which reproduce the appearance close to the target color and translucency.

18:30 (New York)
00:30 (Paris) / 08:30 (Tokyo)

JIST-First: Spectral Estimation of Multiple Light Sources based on Highlight Detection, *Shoji Tominaga[1,2], Keita Hirai[3] and Takahiko Horiuchi[3], [1]Norwegian University of Science and Technology (Norway), [2]Nagano University (Japan), and [3]Chiba University (Japan).* **327**

The authors discuss the spectral estimation of multiple light sources from image data in a complex illumination environment. An approach is proposed to effectively estimate illuminant spectra and the corresponding light sources based on highlight areas that appear on dielectric object surfaces. First, the authors develop a highlight detection method using two types of convolution filters with Gaussian distributions, center-surround and low-pass filters. This method is available even for white surfaces, and it is independent of object color and of viewing and incidence angles. Second, they present an algorithm for estimating the illuminant spectra from extracted highlight areas. Each specular highlight area has a spectral composition corresponding to only one light source among multiple light sources. The spectral image data are projected onto a two-dimensional subspace, where a linear cluster in pixel distribution is detected for each

highlight area. Third, the relative positional relationship between highlight areas among different object surfaces is used to identify the light sources on each surface. The authors develop an algorithm based on probabilistic relaxation labeling. The light source for each highlight and the corresponding spectral-power distribution are determined from the iterative labeling process. Finally, the feasibility of the proposed approach is examined in an experiment using a real complex environment, where dielectric objects are illuminated by multiple light sources of light-emitting diode, fluorescence, and incandescence.

2-MINUTE INTERACTIVE (POSTER) PREVIEWS VI FOLLOWED BY INTERACTIVE SESSION VI AND BREAK

Session Chair: Masaru Tsuchida, NTT Corporation (Japan)

18 NOV: 18:50 – 19:40 (NEW YORK)

19 NOV: 00:50 – 01:40 (PARIS) / 08:50 – 09:40 (TOKYO)

Interactive (Poster) Paper authors provide a brief overview of their work, followed by talks with authors in individual Zoom rooms. Posters may also be visited via Perusall (see directions within the conference portal) at any time.

Double Ring Model for Foveated Imaging, *Hiroaki Kotera, Kotera Imaging Laboratory (Japan)* **336**

Human visual system has a space-variant resolution nature. In the retinal receptive field, the resolution is not uniform but sampled finest in the central fovea and coarser in the peripheral. This variable resolution mapping function is born by the cerebral primary visual cortex V1. It has a clear visual field map of spatial information, and this spatial mapping structure is called Retinotopy. The forward mapping to visual cortex from retina is characterized with complex LPT (Log-Polar-Transform) by Schwartz. The retinal receptive field image is reconstructed by inverse projection LPT-1 from V1. This reconstructed process is called Foveated Imaging. Since the spatial information is concentrated in the center of the visual field, the Foveated Imaging is applied to image compression, pattern recognition, robot vision, and/or computer vision. The retinal receptive field image is suitable for material appearance expression with natural blurring due to peripheral vision.

However, the complexity of the inverse transform LPT-1 was a bottleneck. This paper proposes a Double-Ring-structured novel Foveated Imaging method using positive and negative Gaussian blur masks without using the inverse transform LPT-1 of Schwartz theory and reports the evaluation of reproduction errors.

Image-based Measurement of Structural Color Using Spectral Camera, *Kazuki Iwata, Hiroki Shirasawa, and Keita Hirai, Chiba University (Japan)* **342**

We perceive structural colors by optical phenomena such as light interference and diffraction caused by a fine structure of the object surface. One of the characteristics of structural colors is that a wavelength distribution of light changes depending on an incident angle of a light source and a viewing angle. Generally, for color evaluation and reproduction, it is required to acquire reflection characteristics of objects. Therefore, BRDF (Bidirectional Reflectance Distribution Function) is often used as a function that represents reflection characteristics depending on incident and viewing angles. In this study, we measured BRDF of structural colors based on a method to acquire image-based material reflection characteristics using a spectral camera. The measurement was performed by aligning an optical axis of a spectral camera with a structural color sample and changing an irradiation angle of a light source. Reflection characteristics were represented by using a radiance factor, which was a ratio between a spectral radiance of white material and that of structural color. From measurement results, we confirmed an angle-dependent radiance factor. Finally, based on a measured spectral radiance of a structural color sample, we spectrally reproduced the structural color using a spectral projector based on model fitting of spectral data.

Digital Camera-based Spectral Estimation in Open Environment based on Imaging Condition Correction, *Jinxing Liang, Wuhan Textile University (China), and Kaida Xiao, University of Leeds (UK)* **347**

Digital camera-based spectral estimation in open environment is a challenge in current stage. Although some methods have been proposed in recent years, the methods do not consider the exposure inconsistency between camera spectral characterization and spectral estimation applications, that makes the proposed method cannot for practical applications. We proposed here a spectral estimation method based on imaging condition correction of which can deal with the problem exist in current methods. Using the whiteboard and raw camera response, the imaging conditions of open environment is recorded and corrected to the reference imaging conditions, and the surface spectral of object is estimated using the established spectral estimation matrix in the reference imaging conditions. The proposed method in three application models are tested and compared. The result shows that the adaptive model for imaging condition correction gives the best spectral estimation accuracy.

A Study of Unsharp Masking on HDR Visualization on Low Dynamic Range Devices, *Jakkarin Singnoo, Chulalongkorn University (Thailand)* . **351**

To visualize HDR contents on low dynamic range displays, a fast and efficient TMO is often preferred. One way to achieve this is to use a Global TMO. However, Global TMO often results in poor contrast tone-mapped images and often needs a postprocess that enhances the contrast, such as Unsharp Masking. This work illustrates that such Unsharp Masking can be directly integrated into several global TMOs, resulting in an alternative framework to apply the Unsharp Masking to the HDR visualization pipeline. The proposed framework is fast and delivers images with a proper contrast without the need for the additional image sharpening at the post process.

COLOR APPLICATION SESSION IV

Session Chair: Nicolas Bonnier, Apple, Inc. (US)

18 NOV: 19:40 – 20:50 (NEW YORK)

19 NOV: 01:40 – 02:50 (PARIS) / 09:40 – 10:50 (TOKYO)

19:40 (New York)
01:40 (Paris) / 09:40 (Tokyo)

Simultaneous Measurement of BRDF and Surface Curvature by Using Pattern Illumination, *Shinichi Inoue and Norimichi Tsumura, Chiba University (Japan)* **356**

In this study, we propose the simultaneous measurement method of the bidirectional reflection distribution function (BRDF) and the radius of curvature by using pattern illumination. For nonplanar objects, the angle of reflection light changes according to the surface normal angle of curved object. Therefore, it is necessary to consider the effects of curved surfaces when measuring the BRDF on non-planar surfaces. We suppose a convex surface that can be represented by a constant radius of curvature. The pattern of illumination was generated by placing the illumination mask with pattern apertures in the incident light path of the BRDF measurement apparatus in which the incident light is collimated light. We developed the measurement apparatus. We measured four types of sample with different BRDFs on three different radiuses of curvature. The results showed that the

BRDF and the radius of curvature can be measured simultaneously by using the pattern illumination.

20:00 (New York)
02:00 (Paris) / 10:00 (Tokyo)
A New Independent Dataset to Verify the Performance of Colour Appearance Models for Predicting Simultaneous Contrast Effect, *Yuechen Zhu[1], Dalin Tian[1], and Ming Ronnier Luo[1,2]; [1]Zhejiang University (China) and [2]University of Leeds (UK)* **361**
A web-based experiment was conducted worldwide including eight universities from four countries. An independent and comprehensive dataset considering three colour attributes (lightness, chroma, and hue) and cross-term effects was accumulated for verifying the prediction performance of colour appearance models on simultaneous colour contrast effect using categorical judgement method. The small observer variation indicates that the web-based method is robust for this experiment while offering convenience and large scale. CCZ model derived from the authors and CCW model proposed by Wu and Wardman using Hunt94 model's colour contrast adaptation functions were tested. The results show although the latter gave a good performance on lightness contrast, the predictions on hue, chroma, and cross-terms were unsatisfactory. The CCZ model performed well on all of the types of contrast effects, especially the lightness and chroma contrast. Although the result was slightly scattered for the hue contrast, it still gave a good consistency.

20:20 (New York)
02:20 (Paris) / 10:20 (Tokyo)
Observer Metamerism to Display White Point between LCD and OLED Displays, *Minchen Wei[1], Yu Hu[1,2], and Ming Ronnier Luo[2]; [1]The Hong Kong Polytechnic University (Hong Kong) and [2]Zhejiang University (China)* **366**
Displays with different primary sets were found to introduce perceived color mismatch between pairs that are computationally metameric and to affect the degree of observer metamerism. OLED display is becoming more and more popular than LCD display in different imaging systems. In this study, human observers used an LCD and eight OLED displays to match the color appearance of a D 70 white stimulus produced by a spectrally tunable LED device. It was found the chromaticities of the LCD display were significantly different from those of the OLED displays to achieve a match. When the colors were adjusted to have matched appearance, the chromaticities of the OLED displays were always shifted towards closer to the blackbody locus using the CIE 1931 Color Matching Functions (CMFs). The results also suggested that the CIE 2006 2° Color Matching Functions had the best performance.

20:40 – 20:50 (New York)
02:40 – 02:50 (Paris) / 10:40 – 10:50 (Tokyo)
Closing Remarks
Short Course Co-chair Eric Walowit, independent consultant (US)

DAY 4: WORKSHOPS
THURSDAY 19 NOVEMBER / FRIDAY 20 NOVEMBER

WORKSHOP 1
SKIN CHARACTERISTICS MEASUREMENT, PERCEPTION, AND APPLICATIONS

Convener: Kaida Xiao, University of Leeds (UK)
Speakers: Kumiko Kikuchi, Shiseido Co. Ltd. (Japan); Ming Ronnier Luo, Zhejiang University (China); Nobutoshi Ojima, Kao Corporation (Japan); and Yan Lu, University of Leeds (UK)

19 NOV: 04:00 – 06:30 (NEW YORK) / 10:00 – 12:30 (PARIS)
18:00 – 20:30 (TOKYO)

There has recently been a resurgence in interest in skin characteristics, driven by a number of different technologies and application areas where accurate skin measurement and reproduction are key factors. Application areas include the diagnosis of cutaneous diseases, segmentation for face detection and recognition, reproduction for the graphic arts, and matching for body and maxillofacial soft tissue prostheses. For such applications, a comprehensive knowledge of the range of skin shades that represent individuals, an understanding of how skin characteristics varies, and how people perceive these differences in a wide range of viewing conditions are strongly desired. The goal of this workshop is to bring together practitioners and academics from a range of disciplines to explore the outstanding issues in the measurement, reproduction, and perception of skin, with a particular emphasis on skin imaging.

WORKSHOP 2
COLOR IN THE ARTS

Convener: Carinna Parraman, Centre for Fine Print Research, University of the West of England (UK)

19 NOV: 11:00 – 13:30 (NEW YORK) / 17:00 – 19:30 (PARIS)
20 NOV: 01:00 – 03:30 (TOKYO)

Color is fundamental across sciences, theology, languages, and technology, and for many centuries, has been inextricably bound to art and design. As symbolic, therapeutic, synaesthetic or surreal, it has the power to give pleasure or discomfort. As a sensation, Josef Albers described the properties and relationship of color in art, that 'deceives continually'.

Color has drawn artists and scientists into fierce debates. Newton's experiments on the phenomena of light and exploration on pigments were not without adversaries. William Blake regarded Newton as lacking in imagination. The poet John Keats decried Newton had 'destroyed the poetry of the rainbow by reducing it to a prism'.

Artists for centuries explored and captured the appearance of materials through pigments and drawing. Sometimes creating the most lifelike images that one could ask, is this a photo or a painting? Color is reflected and transmitted by its medium—as pigments, textiles, light and film, as structural color that appears in glass and pottery, iridescent surfaces such as feathers and beetles, or inter-reflections between colored objects and surfaces.

This workshop calls upon artists, designers, and historians to discuss the complexities of color in the arts.

Now You See It, and Now You Don't: Illusive Colour, *Susanne Klein, Centre for Fine Print Research, University of the West of England (UK)*
Colour, as beauty, lies in the eye of the beholder. In 1861, based on the RGB model of colour perception, James Clerk Maxwell produced the first colour photographs by exposing black and white film through red, green, and blue filters, thus recording intensity patterns, but not colour itself. Going back to Maxwell's recording method and printing the result as lithography or Woodburytype in cyan, magenta, and yellow or with red, green, blue speciality pigments allows to explore 'true' colour and empowers the artist to intervene at all stages of the process. Knowing that three black and white negatives are being created rather than a colour one changes the approach as well as the result. The recording process is slow. The filters have to be changed between each image. Control, direction, and choices made in advance of taking the picture change the dynamic between the photographer the scene or the sitter. Time is traced by coloured ghosts in the final print. Striving for a defined set of process colours at the printing stage rather than manipulating colours in film processing allows the photographer to consciously engage with the subject and visualise other senses, such as smell, noise and mood.

Colour in the History of the Eye, *Abigail Trujillo, Centre for Fine Print Research, University of the West of England (UK)*
Colour cannot be separated from the human experience, neither the significance of colours can be understood without the framework of a cultural worldview. Early uses and representations of colours in the arts manifest the technological development of an era, as well as an approach to the nature of vision, human values, perception, and consciousness. In this presentation, I will review ancient polychromy and some of the great moments of colour in the history of painting. I will address historical examples where colours became the kernel of cultural order, the symbols of life, death, power, virtue and we will seek for an insight on the mysteries of the aura drawing upon our modern understanding of light.

Adventures in Colour and Appearance, *Carinna Parraman, Centre for Fine Print Research, University of the West of England (UK)*
This presentation seeks to explore how artists have observed the illumination and colour appearance of objects and scenes, and by using pigments to reproduce the appearance. One of the first paintings to draw me into an investigation of colour phenomena was a painting of Henri Matisse by André Derain (1905) in the Tate Gallery, London. Matisse's portrait is rendered as a full polychromic painting, one side of his face is painted blue, and the other side of his face is yellow. I was interested in this painting because it represented to me a range of open issues around the subject of colour and illumination; how appearance is captured and reproduced, and our capacity as humans to see and process the world differently. This presentation will draw upon artists who have used colour in art in different ways.

The Material is the Colour, *Angela Thwaites, practicing glass artist (UK)*
Like the screens we use every day, we are steeped in colour. Even black and white as seen through a screen is made up of a multitude of colours from violet to burnt yellow passing through grey, blue, sepia brown, resulting in an overall impression that we accept as a black and white image. The medium that enables us to see this and to carry out our 21st-century lives is glass. Long before we were all working and living through screens, I began to explore glass as an expressive sculptural material. Glass drew my interest away from ceramics in the way screens capture and hold our attention now. Light, transparency/translucency, abstraction of mass and scale and of course colour are qualities which stole my imagination as an artist and fascinate me still: colour for embodying form and space, symbolism and language, for storytelling and humour, for sensitivity and for power. Whereas other materials take on a patina or a surface layer of colour, glass is the colour.

Colour and Textiles, *Becky Gooby, Centre for Fine Print Research, University of the West of England (UK)*
The British Interwar period was a time of significant textile technological modernisation, change and innovation, with the advent of cheap, chemical colourants, synthetic fabrics, and the emergence of silk screen textile printing. Britain's housebuilding boom meant that homeownership and interior decoration were available to the masses. The colour palettes selected from my archival research, incorporating smoky, dark colours, neutrals, and earth colours, have proven to be the hardest to reproduce in digital textile printing (DTP) accurately. These palettes provide a challenge to test, document, and trail DTP methods, which aim to aid colour assurance and accuracy for this emerging technology. This presentation offers a comparative case study and asks what lessons can be learned and incorporated into best practice for developing DTP technology today.

WORKSHOP 3
OPEN TABLE ON THE FUTURE OF COLOR RESEARCH

Convener: Javier Vazquez-Corral, Universitat Pompeu Fabra (Spain)
Speakers: Michael Brown, York University (Canada); Jan Morovic, HP Inc. (UK); and Philip Urban, Fraunhofer Institute for Computer Graphics Research IGD (Germany)

19 NOV: 11:00 – 13:30 (NEW YORK) / 17:00 – 19:30 (PARIS)
20 NOV: 01:00 – 03:30 (TOKYO)

Color imaging received a lot of attention during the rise of the smartphone era—especially due to its associated cameras—and this is still the case, as different manufacturers use the quality of the photos obtained to publicize a new phone. The fight between these companies has garnered lots of attention in some specific research areas, such as image quality and image fusion. Currently, it seems we are again at a turning point with the advent of new technologies such as AR/VR, 3D printing, wide color gamut, and HDR, to name just a few. During this round table, world-leading color scientists will debate on these topics, looking specifically at where we have come from in color imaging research and where we are heading.

WORKSHOP 4
VR/AR/MR APPEARANCE AND PERCEPTION

Convener: Minchen (Tommy) Wei, The Hong Kong Polytechnic University (Hong Kong)
Speakers: Romain Bachy, Facebook (US); Kynthia Chamilothori, TU/e (the Netherlands); Trisha Lian, Facebook (US); and Michael Murdoch, Rochester Institute of Technology (US)

19 NOV: 19:00 – 21:30 (NEW YORK)
20 NOV: 01:00 – 03:30 (PARIS) / 09:00 – 11:30 (TOKYO)

With the development of various new imaging technologies, virtual reality (VR), augmented reality (AR), and mixed reality (MR) are becoming more and more popular for use in various industries for different purposes. Little research, however, has been carried out to investigate issues related to appearance and perception when using these new technologies. To facilitate the development and to improve the user experience, a comprehensive understanding about how the human visual system responds to stimuli and scenes produced by VR/AR/MR is important. In this workshop, speakers present the latest research and have an open discussion about outstanding issues that need scientific research.