Scoping review on automatic color equalization algorithm

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Abstract. Digital image processing is at the base of everyday applications aiding humans in several fields, such as underwater monitoring, analysis of cultural heritage drawings, and medical imaging for computer-aided diagnosis. The starting point of all such application regards the image enhancement step. A desirable image enhancement step should simultaneously standardize the illumination in the image set, possibly removing bad or not-uniform illumination effects, and reveal all hidden details. In 2002, a successful perceptual image enhancement model, the automatic color equalization (ACE) algorithm, was proposed, which mimics the color and contrast adjustment of the human visual system (HVS). Given its widespread usage, its correlation with the HVS, and since it is easily implementable, we propose a scoping review to identify and classify the available evidence on ACE, starting from the papers citing the two funding papers on the algorithm. The aim of this work is the identification of what extent and in which ways ACE may have influenced the research in the color imaging field. Thanks to an accurate process of papers tagging, classification, and validation, we provide an overview of the main application domains in which ACE was successfully used and of the different ways in which this algorithm was implemented, modified, used, or compared. © 2021 SPIE and IS&T [DOI: [10.1117/1.JEI.30.2.020901](https://doi.org/10.1117/1.JEI.30.2.020901)]

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1 Introduction

The starting point of this scoping review is the automatic color equalization (ACE) algorithm.^{1–3} This algorithm is part of the spatial color algorithms (SCA) family,⁴ a group of algorithms that mimic the human visual system (HVS), enhancing contrast and colors according to the spatial distribution of pixels values in the scene.¹ The SCAs are mainly based on the visual mechanism for which color sensation depends on the spatial arrangement of the stimuli in the scene. This mechanism has been well studied and employed in many fields (e.g., art, design, psychology, and optometry), where it is well known that identical color stimuli can originate different color sensations according to their distribution in the image. An example of this phenomenon is the visual illusions (e.g., simultaneous contrast). In general, SCA enhancement is based on a qualitative estimate of the appearance of each point according to the influence of the surrounding spatial arrangement of the scene. This principle is derived from Retinex,^{5,6} the first computational model of color sensation, founding member of the SCA family from which ACE derives.²

ACE is easily understandable, implementable, and applicable and allows the user to enhance the image depending on its content and on pixels spatial arrangements, thus simulating some of the main behaviors of the HVS. Nevertheless, ACE computational costs are $O(n^2)$, where n is the number of pixels in the image, thus the high computational costs are the main disadvantage of ACE. As presented in the next sections, speed-up methods have been devised to overcome this limit.

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Fig. 1 Example of ACE application on images from the dataset Ex-Dark⁷ and NPRgeneral.⁸

In this research, we show that since its presentation ACE has been widely used, mathematically formalized, and even reimplemented for optimizing its computational performance so that it is currently used as one of the preprocessing steps of different applications in disparate fields and image enhancement workflows. The technical reasons determining the success of this image enhancement algorithm may be quite different, e.g., the visual quality of the output images, the normalizing effect on images illumination, or its easy implementation (see Fig. 1). Due to ACE correlation with the HVS, the output images are enhanced in contrast and colors as observers would expect/like to see them and are therefore usually preferred compared to the original.^{9–11} Due to ACE properties, this algorithm and this scoping review can be of interest to researchers addressing the problem of color constancy both for machine vision and human vision applications. Moreover, when a dataset where images characterized by different illumination conditions are treated, ACE, like other SCAs,¹² has the useful property of normalizing the effects of the illumination, therefore producing a more uniform dataset. An overview of the different implementations of ACE is presented in Sec. 4.2.2, anyway different implementations are also available online (among the different ACE implementations, the following one is available in Python language).

Another advantage of ACE, which makes this algorithm widely usable and applicable, is that it does not require user supervision, statistic characterization, *a-priori* information on the scene, nor data preparation. Moreover, ACE presents just a single parameter to tune [r in Eq. (1)], which is easily understandable and manageable, so that also nonexpert users can apply and use this algorithm to achieve the desired image enhancements.

In this scoping review, we selected ACE among the whole family of Retinex-based algorithms, because it has a medium-high citation score, it is easily implementable, and correlated with the HVS. For these reasons, from the study of ACE applications and roles, we can understand and define the main needs and research directions in the SCAs field, to define new trends and directions to improve the research on spatial models and algorithms able to deal with complex scenes in a global and local approaches. More specifically, in this work, we are interested in the identification and analysis of the application domain and roles of ACE and in the mapping of these characteristics. To this aim, we have collected and analyzed a wide set of papers using it.

Following the indications reported by Munn et al.,¹³ a scope review has been considered more appropriate at this purpose, instead of a systematic review, since we do not aim at produce a critical answer to specific queries but to provide an overview of evidence. Thus, as suggested by Peters et al.,¹⁴ an assessment of methodological limitations or biases of the papers included in the study is not performed, and we focus on identifying and examining the applications and roles of ACE in the many researches using and citing it. The goal of this scoping review is to better understand the motivations behind the many different ACE applications and roles, to define the main needs, and provide the scientific community with new research directions.

The research methodology of this study is presented in Sec. 3, and in Sec. 4 the results are discussed.

2 Automatic Color Equalization

ACE was presented for the first time in 2002 at the *Conference on Colour in Graphics, Imaging, and Vision*³ and published in 2003 by Rizzi et al.¹ SCA family of algorithms tries to simulate some characteristics of the HVS enhancing images with a global and local approach, from the idea that color sensation derives from the spatial ratios of the reflected light intensity in specific wavelengths bands computed between adjacent areas of the image. One of the main characteristics of ACE¹ is the integration of local and global gray world (GW) and white patch (WP) approaches. The local WP accounts for color adjustment while the GW accounts for an automatic local adjustment of average lightness and contrast.

Like all SCA algorithms, ACE is performed in two stages. In the first stage, the chromatic and spatial adjustment produces an output image, in which every pixel is recomputed due to the image content. In the second stage, the use of image dynamic range is maximized, by normalizing the white at a global level.

ACE works by comparing every pixel p_t in the image I to every other pixel independently in the RGB channels and summing all the difference to compute the final value:

$$p_{\text{new}} = \frac{1}{k_t} \sum_{p_j \in I, p_j \neq p_t} r(p_t - p_j) d(t, j), \quad (1)$$

$$k_t = \sum_{p_j \in I, p_j \neq p_t} d(t, j). \quad (2)$$

Before the sum, each difference is modified by a nonlinear function $r(\cdot)$ and weighted by $d(\cdot)$, the inverse of the Euclidean distance among the pixels p_t and p_j . The normalizing factor k_t is used to avoid border effect (i.e., overamplifications of local differences along the edges in the image content). The factor $r(\cdot)$ is the truncated gain function:

$$r(p_t - p_j) = \begin{cases} -1 & \text{if } (p_t - p_j) \leq -thr \\ \frac{(p_t - p_j)}{thr} & \text{if } -thr < (p_t - p_j) < thr \\ 1 & \text{if } (p_t - p_j) \geq thr \end{cases} \quad (3)$$

This last function is a nonlinear amplification of the normalized difference between pixel values, responsible of the final pixel changes. The final contrast level depends on the slope value of $r(\cdot)$; the higher the slope, the higher the contrast.

A comparison and first evaluation of the performance of the two main SCA, Retinex and ACE, is presented by Rizzi et al.² In this second paper, the ACE algorithm is presented under a different light, and its computational model is compared with Retinex, to underline their peculiar characteristics and promote a more specific and aware use of those two algorithms. The two algorithms present similar properties of global and local enhancement for what concerns lightness, color constancy, and dynamic range stretching, and when applied to visual illusions (such as images of simultaneous contrast) both compute visual appearance presenting the same values of hue, but different brightness and saturation (see Ref. 2). Beside the steps of input and output data calibrations,⁴ the main difference between ACE and Retinex is that Retinex is a WP algorithm, whereas ACE integrates a GQ compensation mechanism.²

In this paper, Refs. 1 and 2 will be considered as the first two papers that presented the ACE algorithm and promoted its performance among the algorithms of the Retinex family.

3 Methodology

For this scoping review study, we partially applied the guidelines described in Refs. 13 and 15. Scoping studies follow five main stages:¹⁵ research question identification, relevant studies identification, study selection, data charting, and results discussion. Following the suggested steps of scoping review, this study was structured in seven different phases:

- Research question definition;

- Relevant studies identification;
- Papers selection;
- Tagging;
- Classification;
- Validation;
- Analysis and discussion.

Main characteristic of this work is that, after the research question definition, we identified the available evidence searching for works citing the two founding papers on ACE algorithm, described in Sec. 2.

3.1 Research Question Definition

As introduced in Sec. 1, aim of this scoping review is to better understand the motivations of the many different ACE applications and roles. At this scope, this study is aimed at finding answers to a specific research question: “After almost 20 years from its first publication, to what extent and in which ways the ACE algorithm may have influenced the scientific research in the color imaging field?” We considered two dimensions for organizing this study:

- (D1) Application domains: in case of practical use of ACE algorithm, the domains in which the method has been applied have been considered for classifying the citing works.
- (D2) Roles: we classified the citing works considering the role the ACE paper(s) had in the described studies.

3.2 Relevant Studies Identification

As starting point of our study, we selected two of the fundamental papers of ACE that have been described in Sec. 2:

- Paper A: Rizzi et al. (Ref. 1);
- Paper B: Rizzi et al. (Ref. 2).

To find answers to our research question, we searched for all papers citing paper A and/or paper B. To do so, we decided to interrogate both Google Scholar and Scopus.

For searching the citing papers on Google Scholar, we used Publish or Perish, an application that retrieves and analyzes academic citations (Harzing’s Publish or Perish¹⁶). One of its features allows one to query Google Scholar for a specific paper and to also search for the works citing it. For paper search on Scopus, we first used Publish or Perish feature as described above, and we retrieved all citing works on Scopus website.

We repeated these two steps for both paper A and paper B, and we combined the results into one comprehensive spreadsheet. The search was performed on November 22, 2019, and we did not specify a time range, so the upper date range limit coincides with this date. The search activity provided 826 results. For each paper resulted in the search phase, we filled in a line in the spreadsheet, completing all columns detailed in Table 1.

3.3 Paper Selection

In this phase, we defined five exclusion criteria that we used to decide whether a paper was to be excluded or included in the study:

1. Language: we excluded all papers that are written in languages different from English and Italian (this choice is due to the authors’ native language).
2. Type: we did not include in the study BSc and MSc theses, books and monographs, invited talk papers, papers from repositories and archives (those only available on ArXiv, ResearchGate, or institutional archives), technical reports, project deliverables, white papers, and other online content that are not scientific peer-reviewed papers (such as blog posts).

Table 1 Columns of the spreadsheet used for the study.

Column	Description
ID	Each paper was assigned with a unique identifier used to identify it in the discussion among the researchers
Title	Complete title of the paper
Author	List of paper's authors
Year	Year of publication of the paper
Source	Name of the source (e.g., journal title in case of a journal article, book title in case of a book chapter, name of the conference in case of a paper included in proceedings, nothing in case of PhD dissertation)
Reference	Complete reference of the paper
ACE paper	Indication of which of the reference papers is cited (i.e., A or B)
Scholar query	Checked if the paper appeared in results of the query on Google Scholar
Scopus query	Checked if the paper appeared in results of the query on Scopus
Citations	Number of citations of the paper
Type	Types of paper (i.e., journal, chapter, proceedings, and PhD dissertation)
Included	Checked if the paper was included in the study
Self-citation	Checked if one or more of the paper's authors are also authors of paper A and paper B
App domain	The domain of application described in the paper
Roles	Used to describe why paper A and/or paper B were cited (i.e., use of ACE, comparison of methods, implementation of ACE, modification of ACE, state of the art/survey, formalization of ACE)

3. Duplicates: if a paper resulted both in search results in Scopus and Google Scholar, we excluded the less-complete result.
4. Multiple citations: if a paper cited both reference papers we excluded one of the two.
5. Errors: we excluded those papers that appeared in the results but did not cite the reference papers or those that listed them in the references list but did not cite them in the text.

At the end of this phase, once the exclusion criteria were applied, the papers included in the study were 298 (the excluded were therefore 528). The included papers are listed in Table 2.

3.4 Tagging

We divided the 298 papers into three sets that were assigned to each of the three researchers (i.e., three of the paper's authors) that actively performed the study. During this phase, the researchers identified the papers written by at least one of the authors of the reference papers: Daniele Marini, Carlo Gatta, and Alessandro Rizzi. Those papers have been tagged as self-citations. Out of 298 papers, only 63 were self-citations (21.14%).

A graphical representation of the distribution of papers according to their type and considering both self-citation papers and papers written by other authors is shown in Fig. 2.

Moreover, Fig. 3 shows the distribution of the papers over the years.

We also performed an analysis to investigate where ACE is more diffused and in what sector it has been used the most (academy or industry). To do so, we considered the affiliation and the relative country of the first author (or the corresponding one). As shown in Fig. 4, China is the country with the highest number of papers (44), followed by Spain (17), France (21),

Table 2 Table of the papers included in the literature review.

Year	Journal	Proceedings	PhD thesis	Chapter
2003	17	18 to 21	—	—
2004	—	22 to 25	—	—
2005	26,27	28 to 34	—	—
2006	35 to 38	39 to 49	—	—
2007	50 to 58	4, 10, 59 to 66	67, 68	—
2008	69 to 72	73 to 78	—	—
2009	79 to 84	85 to 100	101	—
2010	102 to 107	108 to 116	—	—
2011	117 to 124	125 to 133	—	—
2012	134 to 141	142 to 146	147	148
2013	149 to 155	156 to 164	165, 166	—
2014	167 to 181	182 to 186	—	187
2015	188 to 207	192, 208 to 214	215, 216	217 to 220
2016	221 to 236	237 to 245	—	246
2017	9, 247 to 264	265 to 267	268, 269	270
2018	271 to 287	238, 288 to 294	295, 296	—
2019	297 to 305	306 to 310	—	311

Fig. 2 Distribution of the papers according to their type.

United States (18), and Italy (17). As to the sector, out of the 235 papers that are not self-citation papers, only 8 are published by private companies; the other 227 are all written by academics. The eight industry papers have been published by researchers/practitioners in United states (2), Russia (2), Brazil (1), France (1), Germany (1), and Italy (1).

Fig. 3 Distribution of papers over the years.

Fig. 4 Geographical distribution of the papers (the country of the institution of the first or the corresponding author has been considered).

3.5 Classification

Keeping the same assignment done for the tagging phase, the researchers independently analyzed and classified their set of papers by completing the other columns in the spreadsheet:

- Reference: the reference to the paper, in BibTeX format
- Application domain: this column is linked to the second dimension of this study (D1: application domains). Each paper was assigned to an application domain. The list of domains was finalized *a posteriori*, because the selection of its items was guided by the individual classifications of the researchers.
- Roles: this column is linked to the first of the two dimensions used for organizing this study (D2: roles). We classified each paper selecting one of the following values:
 - Comparison;
 - Formalization;
 - Implementation;
 - Modification;
 - State of the art/survey;
 - Use.

3.6 Validation, Analysis, and Discussion

For validating the classification done in the previous phase, the researchers exchanged their subset among them (researcher A validated researcher B, researcher C validated researcher A, and researcher B validated researcher C).

Finally, the researchers met to analyze and discuss the results of the study and to organize them for the preparation of this paper.

4 Results

4.1 D1: Application Domains

The analysis of the papers pointed out that only a limited number of papers are associated with a specific application domain: 84 out of 298 (28.19%).

The distribution of the 84 papers according to the application domain they describe is illustrated in Table 3. The first column lists all the application domains identified during the study while the second and the third columns show the number of papers published by the same authors of paper A and paper B (32 papers, 38.10%) and the ones published by other authors (52 papers, 61.90%), respectively.

Table 3 Application domains identified during the study and distribution of the papers according to this classification.

Application domain	Self-citation papers	Other authors
Advertising posters	1	0
Art	0	2
Astrophotography	3	0
Biology	0	1
Color	2	1
Cultural heritage	3	1
Fish behavior monitoring	0	1
High dynamic range	1	0
Image enhancement	2	19
Image fusion	0	1
Image quality	2	3
Interfaces	3	0
Medicine	0	3
Movies	10	2
Printing	1	0
Psychophysical studies	2	0
Steel bridges	0	1
Stereo images	1	0
Underwater imaging	0	12
Virtual reality	1	0

Focusing on the paper written by other authors, it is quite clear that “image enhancement” and “underwater imaging” are the most diffused application domains in which ACE algorithm has been used with 19 and 12 papers, respectively. In what follows, all the 52 papers will be briefly presented and discussed from the application of ACE in the specific application domains.

4.1.1 *Movies and film restoration*

In Ref. 271, the process of digitization, color enhancement, and digital restoration of a specific type of movies, the reversal films, is illustrated. Reversal films produce a positive image on a transparent celluloid base, with a low cost approach that has been very popular in the 20th century. In the paper, the authors faced specifically one of the main degradation phenomena that affects the reversal film, due to aging process: color dye fading. In Ref. 125, the authors discussed the vulnerability of motion pictures archives, especially the problems related to distortions, such as color fading.

4.1.2 *Cultural heritage*

As an example of cultural heritage preservation and restoration, Ref. 142 focuses on a collection of old colored postcards from the 19th century. This particular kind of document is made of a type of paper that tends to become brown and yellow with the passing of time. Moreover, the pigments of the postcards become faded and also other problems may occur, such as humidity or fungi.

4.1.3 *Art*

ACE algorithm, in Ref. 39, is used for a nonphotorealistic image rendering. In this work, Lam et al. aim at creating an image processing system where the output image that looks like the input but with an artistic twist. In this application, ACE is used to enhance dull colors into vivid ones for cartoon- or comics-like renderings. In the art application domain, the authors of Ref. 40 presented a study made on nonphotorealistic rendering, a discipline that aims at translating photographs into paintings simulating different techniques and media.

4.1.4 *Underwater monitoring*

Another domain in which ACE has been considered is the one related to the assessment of security and quality of drinking water by the observation of fish behavior. This approach, described in Ref. 221, is based on the monitoring of group of fish put in fish tanks in which water flows in a continuous manner. The behavior of the fish (erratic or even death) is used as indicator of presence of toxins in the water. Instead of monitoring this process, all day long, in a manual way, video surveillance and computer vision techniques are adopted.

4.1.5 *Biology*

Another application domain that is related to fish is the one in which biologists work for automatic recognition of coastal fish; specifically, in Ref. 126, the authors describe their work in Gaoquiao district of Zhanjiang, China, where the automatic identification of fish is made difficult by the water condition (the underwater serious noise, strong, and nonuniform color cast, etc.).

4.1.6 *Color*

Tateyama et al. in Ref. 288 describe a new color enhancement technology, which aims at avoiding color saturation for images displayed on big LED screens or on digitally controllable decorative LED illuminations. In this work, ACE algorithm is used to estimate the wider LED color gamut, in fact this algorithm allows to enlarge the color difference while moving all the input colors inside the destination gamut.

4.1.7 Medicine

In Refs. 85, 86, and 117, an interesting research work on the analysis of dermoscopic skin lesion images is presented. The precise automatic analysis of lesion borders is a very critical task in medicine. The main problems related with poor contrast and lack of color calibration are successfully solved using ACE.

4.1.8 Image enhancement

Morel et al.¹⁶⁷ presented a high pass filter method, which eliminates the effect of nonuniform illumination, preserves image details, and enhances the contrast. In this work, authors compare the proposed method with more complex methods, ACE among them. In Ref. 108, Islam and Farup proposed and analyzed several methods to enhance the output of SCA to preserve the non-neutral properties of the original image along with the enhancement. The results of this paper are promising, also if authors underline the low running time and the possibility to introduce some distortion in the output. In Ref. 41, Chambah presented two methods for correcting nonuniform color casts in images: ACE and progressive hybrid method. In this paper, ACE gives the best results due to its adaptation to different color casts and because it is unsupervised. Lisani in Ref. 289 presented a local image enhancement technique based on a logarithmic mapping adapted on the luminance of each pixel neighborhood. This new technique is inspired by ACE, which is used to make comparisons. In this paper, authors add value mainly to the ability of ACE to adapt to widely varying light conditions. This characteristic inspired also a fuzzy logic-based algorithm, presented in Ref. 87. Here, authors developed a technique to deweather fog-degraded images and use an algorithm similar to ACE in the color correction step. In Ref. 79, Palma-Amestoy et al. devised a set of basic requirements to be fulfilled by models, to be considered “perceptually based.” Due to the translation of human color vision in mathematical assumptions, it was possible for the author to analyze algorithms such as Retinex and ACE. In this paper, authors found that those algorithms effectively enhance details and remove color cast without introducing noise. Furthermore, authors provided processing to avoid noise amplification in extremely dark images.

A color image enhancement method, which applies a weighted multiscale compensation based on the GW assumption, is presented in Ref. 247. ACE algorithm is used to make comparison with the proposed algorithm, due to its ability in preserving color constancy. Results show that images enhanced through ACE and the proposed method have low color differences, but the results obtained using ACE are brighter than those using the second method. A similar work was described by Choudhury and Medioni.¹⁰² Also in this paper, authors developed an algorithm of color enhancement focused on color constancy. This algorithm has the main characteristic to estimate the illumination separating it from the reflectance component in the image. In this work, the new algorithm is compared statistically and subjectively with ACE and other algorithms of the Retinex family.

Wang et al.¹⁶⁸ describe a variational Bayesian method for Retinex (named VBR), which aims at simulating and interpreting how the visual system perceives colors. In the paper, the VBR algorithm was compared with some Retinex and some non-Retinex method, ACE among them. In Ref. 182, authors try to give an answer to the question “What is the right center/surround for Retinex?” To answer this question, authors analyze the formal properties of the center/surround versions of Retinex. From this study, ACE was found to be the best Retinex method considering the conditions imposed in this study.

An algorithm to enhance and denoise low-light images is presented in Ref. 127. The main characteristic of this method is that it uses different color spaces to achieve different enhancements. Results show that the color preservation framework used by the algorithm is satisfactory and can generate higher contrast and sharpness in comparison to ACE and other image enhancement methods. Also in Refs. 80 and 88, Han and Sohn deal with the problem of restoring images taken under arbitrary light conditions. In Ref. 80, an automatic framework: illumination and color compensation algorithm using mean shift and the sigma filter (ICCMS) is presented. In this paper, the results show that all the compared algorithms, ACE among them, increase local contrast and visual perception, but ICCMS performed a better illumination and color enhancement in

underexposed regions of the image. Due to the satisfactory results, in Ref. 88 authors develop a framework inspired by ICCMS color restoration and by the free region-of-interest illumination compensation for digital cameras with touch screen. This method named HRICR allows to restore distorted images taken under arbitrary light conditions. Han and Sohn,⁸⁹ present another framework to restore illumination and color fidelity in digital camera, but unlike the previous method, this latter one is based on a human visual perception model. The proposed method was compared to other algorithms of shadow correction such as ACE. Results show that the proposed method enhances illumination and color in underexposed image regions. Nevertheless in some images it produces an unwanted halo effect with distortions of colors and noise amplification.

Another algorithm to automatically adjust luminance in under- and overexposed images is presented in Ref. 109. This approach is based on a recursive local intensity adaptation defined for each pixel through a nonlinear recursive framework. In this work, the proposed method is mutually compared with different algorithms, and if on some images ACE gives results comparable to the new method, in some cases it introduces color alterations. A method based on histogram equalization is presented in Ref. 222. This method reflects the characteristics of the global histogram equalization method locally to avoid artifacts and produce a global and local contrasts enhancement. The new method is compared with color constancy algorithms such as ACE, and an objective and subjective assessments is provided in the results. In Ref. 149, an improvement of random spray Retinex (RSR) is proposed: the light random sprays retinex (LRSR). The main purpose of the authors is to reduce the noise introduced by RSR and computation costs. In this paper, LRSR is compared with ACE and other algorithms that apply local illuminant correction. Nevertheless all the tested methods differed significantly among them in perceptual difference and computational costs, LRSR gives very similar results to RSR reducing significantly the computation time. The same authors, in Ref. 188, propose a new algorithm, named smart light random memory sprays Retinex (SLRMSR), which is an improvement of LRSR. From the comparison with other image enhancement methods, it was seen that SLRMSR is slightly outperformed by ACE in brightness adjustment and outperforms all other methods. In conclusion, the results demonstrated that SLRMSR is a good candidate for real-time applications due to the high quality of the output and low computational costs. A similar work to optimize the computational time of one Milano Retinex algorithm, STAR, is presented by Lecca²⁷². The performance of the new algorithm, named SuPeR, was compared to other approaches through objective assessment. Results show that SuPeR enhances color images similarly to other Milano Retinex algorithms but with much shorter computation time, also if not in real time.

4.1.9 Image fusion

Image fusion is a technique used for producing a single image from the merge of two or more images. An example of the application of ACE to this domain is given in Ref. 128. The goal of image fusion is to produce a new picture that contains more information than the one included in the single pictures used for the merge.

4.1.10 Image quality

Ouni et al.⁹⁰ present a full reference color metric called spatial color image difference (SCID), which is perceptually correlated with the HVS. In this work, ACE algorithm is used when a reference image is missing; thus, the color difference is computed between the target image and the same image enhanced/restored through ACE. In Ref. 91, ACE has been used for a comparison of methods aimed at addressing the problem of illuminant variation in image recognition. Finally, in Ref. 208, the problem of brightness adjustment in real-time image enhancement process is considered.

4.1.11 Machine and computer vision

One of the most popular applications of machine vision today is pedestrian detection. In our study, three papers reported the use of ACE in this application domain (i.e., Refs. 156, 183, and 273). Another application of ACE to this domain is focused on face detection: in

Ref. 184 improvements in terms of detection performance and evaluation protocols are presented and discussed. Reference 67 presents a study on the use of computer vision applied to painterly rendering. The authors used ACE to link the process to human vision because of the important influence that perception and painting play on one another.

4.1.12 Steel bridges

In Ref. 248, the authors applied different restorative methods to steel bridges photographs to prepare them for bridges health assessments procedures. A discoloration of the coatings is often an important sign of the progressive damage process of steel bridges, but visual inspections may easily lead to errors in human interpretation. To reduce the influence of any environmental noises (e.g., light sources), the distorted colors need to be restored to their authentic ones.

4.1.13 Underwater imaging

In this peculiar application domain, several papers present methods for overcoming problems of nonuniform contrast and poor visibility caused by bad illumination and color cast that are typical in underwater imaging. References 185, 274, 297, 298 present studies that compare some of them. In Ref. 290, a method for addressing nonuniform illumination of underwater images through segmentation and local enhancement (instead of global) is presented. References 143, 144, 187 present the ROV three-dimensional (3D) project that aimed at creating tools for applying underwater photogrammetry and acoustic measurements to underwater archaeology practice. The tools are meant to offer a nonintrusive alternative that would reduce the *in-situ* investigation time. Another study performed in underwater archaeology is presented in Ref. 306 and applies a color enhancement method for reconstructing the 3D model of a shipwreck. Another method is presented in Ref. 157 that is focused on solving problems due to scattering and color distortion. Reference 299 presents an enhancement method, based on Retinex, that applies both on underwater images and videos taking care of low contrast, color degradation, and nonuniform illumination. Finally, in Ref. 295, a PhD thesis, an underwater imaging system based on several algorithms for color and illumination normalization has been presented.

4.2 D2: Roles

In column ROLES of the spreadsheet, we assigned to each paper a description of the way they used the reference papers, choosing by a finite set of values:

- Comparison: ACE is compared with other algorithms;
- Formalization: the paper presents a formal description of ACE algorithm;
- Implementation: the paper illustrates an implementation of ACE algorithm in some programming language;
- Modification: the authors modified ACE algorithm and present their own new version;
- State of the art/survey: ACE is cited in systematic review, state of the art, or related work sections but not used, formalized, implemented, or modified.
- Use: ACE is actually used and its results are presented and discussed.

Figure 5 shows the distribution of the papers according to the roles values and the self-citation/other authors attribute.

4.2.1 Comparison

All the 39 papers that belong to the comparison class cite ACE in a comparison with one or more other methods. We analyzed these papers and identified the methods used by each paper and its frequency of use. We then classified the methods into eight families of methods:

- Bilateral filtering and processing miscellanea;
- Dehazing and underwater various methods;
- Histogram equalization or derived;

Fig. 5 Roles identified during the study and distribution of the papers according to this classification.

- No-reset Retinex;
- Reset Retinex;
- Variant of ACE;
- Variational Retinex;
- WP/GW normalization.

Figure 6 shows the number of methods grouped in the families, whereas Fig. 7 shows how many times methods belonging to the families have been used in the 39 analyzed papers.

4.2.2 Implementation

ACE's implementation by Getreuer has been documented in Ref. 134. Also in Ref. 291, an implementation of ACE is presented.

Fig. 6 The methods used in the 39 papers are organized into families of methods. Here, the number of methods belonging to each family is depicted.

Fig. 7 The chart shows how many times the methods included in the families have been compared with ACE in the 39 comparison papers.

4.2.3 Modification

The authors of Ref. 157 propose a faster version of ACE, called α ACE and tested it on underwater images. Also the work published in Ref. 292 proposes a modified version of ACE, called L-ACE, that uses the acyclic side suppression model for brightness correction and Gaussian distribution to reduce the number of samples.

4.2.4 State of the art/survey

In this section, we discuss the most cited papers that cite ACE algorithm in the systematic review, in the state of the art, or in related work sections. The papers that result in this classification are 200, with the exclusion of the ones that present self-citations, the considered papers are 174. Among them, the 1.15% has more than 200 citations, the 2.30% has between 200 and 50 citations, the 28.74% between 49 and 10 citations, the 37.93% between 9 and 1 citations, and the 29.89% has no citations. Here, we describe highly cited papers.

The most cited paper, by Meylan and Susstrunk,³⁵ presents a new method for the rendering of HDR images based on the Retinex model. This paper cites the paper B² while exploring the state of the art of Retinex path-based methods. This paper underlines the practical problems of ACE subgroup of algorithms, which have high computational costs and free parameters. Thus, the authors focus on surround-based Retinex models to implement a new HDR image rendering method. The theme of HDR images concerns also a paper made by McCann,⁵⁰ where the author focuses on the theme of veiling glare. Here, ACE algorithm is presented as a computational approach that uses spatial comparison to synthesize the optimal display and to reduce the effect of glare miming the physiological mechanisms such as simultaneous contrast.

A paper with more than 200 citations, which cites ACE as state of the art, was presented by Schettini and Corchs.¹⁰³ This paper is a review of methods and techniques to process underwater images, and authors cite paper A¹ in the section concerning the algorithms of image enhancement and color correction. This paper describes the ACE algorithm and reports some images of its application for the enhancement of an underwater video, but focuses, in particular, on the tests and results presented by Chambah et al.³¹² Similarly, in Ref. 110 by Iqbal et al., ACE algorithm is reported in the state of the art while introducing different image enhancement techniques for underwater imaging. Also in this case, the citation of paper A¹ is presented together with the applications made by Chambah et al.³¹² In this paper, the ACE algorithm is discarded by the authors due to its computational costs. Considering the topic of underwater imaging, the works by Yang et al.¹²⁹ and by Ghani and Isa¹⁸⁹ present two different underwater image processing

methods. In the first paper, the image enhancement algorithm is based on dark channel prior and in the second work, authors propose a technique which applies the histogram modification of the integrated RGB and HVS color models. In both the works, ACE papers A and B are presented as systematic review and no further comments about the algorithm are made.

The Retinex theory and its implementation laid the foundations for many other image enhancement algorithms and ACE is often cited in the state of the art. An example is the paper by Tao and Asari,²⁶ which presents a new image enhancement algorithm called adaptive and integrated neighborhood-dependent approach for nonlinear enhancement and cites ACE paper B in the “related work” section. Furthermore, in Ref. 81, Bertalmío et al. present the kernel-based Retinex algorithm. This algorithm has the same characteristics of the original Retinex and shares some correspondences with ACE model. Similarly, in a work Li et al. in Ref. 135, authors propose a perceptually inspired image enhancement method for correcting uneven intensity in remote sensing images, which is inspired by the Retinex theory. In this work, ACE papers A and B are presented in the state of the art when presenting the Retinex theory and the developed method differs mainly by ACE algorithm because the reflectance is solved within a limited dynamic range and is supposed compliant to gray world assumption. ACE approach to white balancing is discussed also in a work by Kwok et al.¹⁵⁰ In this paper, ACE paper A is cited as state of the art, when reviewing the systematic of the different white balancing methods applied by algorithms of color correction. ACE paper B is cited as state of the art also in a work presented by Tao et al.⁴² in the field of face detection. In this paper, authors describe the multiscale Retinex (MSR) as an effective image enhancement technique and cite ACE as one of the many other implementations of Retinex theory. In this context, the authors discard the Retinex family of algorithms for their application due to some issues in rendering images in complex lighting environment.

Another interesting review was presented in 2006 by Agarwal et al.³⁶ This work introduces a review of the color enhancement algorithms that preserves the color constancy and cites ACE while explaining the Retinex approach. Authors cite paper B² with others implementations of Retinex and then focus on MSR.

The strong correlation between the ACE algorithm and the Retinex theory has been described in several papers. An interesting work, made by Bertalmío and Cowan,⁸² demonstrated the close relationship between Retinex algorithms and the Wilson–Cowan equations (e.g., a set of equations that describe the temporal evolution of the mean activity of a population of neurons in some region of the neocortex), which could result in numerous applications to many neural network problems. In this work, ACE is mentioned to demonstrate this correlation.

Another work where ACE and its family of algorithms is examined for its correlation with visual perception is presented by Hardeberg et al.⁶⁹ Here, the authors evaluate the quality of several color image difference metrics to find out if it is possible to evaluate color gamut mapping using color image difference metrics. In this work, ACE is cited in the future research directions as possible perceptual predictor for the development of new color image metrics that correlate better with HVS.

Since algorithms based on random spray sampling techniques tend to introduce noise in the output, in Ref. 151 a method is presented to reduce noise based dual tree complex wavelet transform coefficients shrinkage. In this work, the RSR and RACE algorithms are analyzed and enhanced, and it was seen that the proposed method produces good quality images, removing noise without altering the underlying image directional structures. An overview of color equalization algorithms is presented in Ref. 217. In this paper, ACE is reported among all the other Retinex family algorithms. Another overview is presented in Ref. 275. Here, different interpretations and mathematical formalization of Retinex model are presented and several color enhancement algorithms with a focus on different variational formulations are described. Since Retinex was widely implemented, in Ref. 190, Zosso et al. made a first overview of the Retinex implementations existing in the systematic and unified them in a single computation framework. Fitschen et al.²⁰⁹ present a variational model for adapting colors of an image based on a defined target intensity image. In this paper, ACE is presented as example of hue preserving color adjustment algorithms.

In Ref. 210, Wang et al. present the technology assisted dietary assessment, a system that automatically identifies and quantifies foods and beverages consumed by the user from mobile images. In this application, ACE is cited in the step of color calibration as a method that combines Retinex with the GW and the WP assumptions.

Huang et al., in Ref. 276, review development of different types of smartphone-based analytical biosensory systems for point-of-care. In this work, ACE paper A¹ is cited in the smartphone-based colorimetric sensors, when underlining the importance of a correct white balance and color correction.

In Ref. 300, different center/surround Retinex algorithms are discussed and the authors provide a quantitative and qualitative analysis to provide suggestion of the best pair of local/global transformations for a center/surround method.

In Ref. 237, the authors propose an image enhancement approach that goes against the common assumption that that underwater images have bluish color cast.

In Ref. 169, the authors present an image enhancement algorithm aimed at conserving the hue and preserve the gamut of R, G, B channels. The intensity input image is transformed into a target intensity image according to a reference histogram. They define a color assignment methodology that makes the enhanced image fit a target intensity image.

Finally, Ref. 108 illustrates and discusses a number of techniques that can be used when a specific application domain demands the preservation of appearance of the original image and not just its enhancement.

4.2.5 Use

ACE algorithm was successfully used in Refs. 39 and 67 for nonphotorealistic rendering. In these studies, authors analyze and describe the functioning of the visual cortex through the analysis and use of computational models. Similarly, in Ref. 40, authors develop a perception-based painterly rendering, including ACE dynamic range-normalization as one function of the developed system. In Refs. 183 and 273, authors present two new pedestrian detection models that provide efficient training and detecting. In both models, ACE is applied on the experimental data-sets before the extraction channel features. This use of ACE is proposed by Benenson et al., in Ref. 156. Here, authors use ACE algorithm as global image normalization before computing the three image channels in a system of object detection. ACE algorithm was found useful also to de-weather fog-affected images, as presented in Ref. 87. In this work, ACE is used in the color enhancement step of the algorithm to restore the natural contrast of the image. Schaefer et al., in Refs. 85 and 117, use ACE algorithm to normalize the colors of dermoscopy images before the segmentation step. In another work,⁸⁶ the same authors archive an accurate segmentation using a co-operative neural network edge detection system, always using ACE in the preprocessing step. ACE algorithm was used in the preprocessing step also in Ref. 184. In this work, a high performing face detector model is presented, and ACE was found successful to enhance the image colors before the detection step. Feng et al. in Ref. 128 propose a new image fusion method. In this work, ACE is used to enhance the colors in the images resulting from the fusion, producing images more useful for human perception or machine vision. In Ref. 126, authors combine a region-based segmentation with ACE algorithm, to segment fish in images with a complex background in water. A new full-reference image quality metric, named SCID is presented by Ouni et al. in Ref. 90. The metric is based on characteristics of the HVS and when an image reference is not available the SCID is combined with ACE. In Ref. 288, ACE is used to enhance the colors for LED illuminants by increasing the color difference between pixels while changing the image color gamut. Prado et al. in Ref. 306 use ACE for 3D reconstruction and virtual reality applications. In this work, ACE is used to perform a color enhancement on the input images before the 3D reconstruction of the Rio Miera wreck ship. Finally, in Ref. 298, ACE is used for color enhancement of underwater images, together with HIST and PCA methods.

4.3 Brief Overview on Self-Citation Papers

4.3.1 D1: application domains

As can be seen in Table 3, some of the application domains that have been identified in this study are only addressed in papers published by the authors of paper A and paper B. These application domains and their occurrences are shown in Fig. 8.

Fig. 8 The application domains used only by papers published by paper A and paper B authors.

- Advertising posters⁹²
- Astrophotography^{238,249,277}
- High dynamic range⁵¹
- Interfaces^{9,17,18}
- Printing¹⁰
- Psychophysical studies^{93,104}
- Stereo images¹¹¹
- Virtual reality²⁸

4.3.2 D2: roles

As visually reported in Fig. 5, only one paper included in this study has been classified as having formalized ACE in a variational form and has been published by paper A and paper B authors.⁵²

4.4 D1 and D2 Interrelation

To conclude the analysis of the data gathered in this study, we want to present some results on the interrelation between D1 and D2, i.e., application domains and roles. Among the six different roles used for classifying the papers, those that present an implementation of ACE, its formalization, or cite it in state of the art/survey sections are not linked to a specific application domain. On the other hand, the papers that cite ACE as comparison with their own method and/or with other methods, and those that modify or use it, most of the times describe a specific application domain.

For the papers published by paper A and paper B authors, of the two papers with role modification, one is linked to image quality, whereas the other has no specific application domain. Out of the 10 comparison papers, 2 have no application domain, whereas the other 8 describe works in astrophotography, color, image enhancement, movies and film restoration, printing, and stereo images. The 23 use papers are all linked to a specific application domain: movies and film restoration, cultural heritage, interfaces, psychophysical studies, advertising posters, astrophotography, high dynamic range, image enhancement, image quality, and virtual reality. Figure 9 shows the details for comparison and use papers.

For the papers published by other authors, of the two papers with role modification, one is linked to underwater imaging, whereas the other has no specific application domain. Out of the 39 comparison papers, 6 have no application domain, whereas the other 33 describe works in image enhancement, underwater imaging, image quality, movies and film restoration, cultural

Fig. 9 The interrelation between D2 and D1 for the self-citation papers classified with role comparison and use.

Fig. 10 The interrelation between D2 and D1 for the papers written by other authors classified with role comparison and use.

heritage, fish behavior monitoring, and steel bridges. The 18 use papers are all linked to a specific application domain: machine and computer vision, medicine, art, image enhancement, underwater imaging, biology, color, image fusion, and image quality. Figure 10 shows the details for comparison and use papers.

5 Conclusions

The scoping review presented in this paper shows the widespread use and implementation of the automatic color enhancement algorithm. The most diffused fields of application of ACE algorithm are image enhancement (25% of the considered papers) and underwater imaging (14.29% of the considered papers). The main roles of ACE, as identified by our study are: state of the art/survey (67.11% of the considered papers) and comparison (16.44% of the considered papers).

In this scoping review, we have found that ACE algorithm is appreciated for its capability of simultaneously standardizing the image illumination, revealing hidden details, and enhancing the image contrast so that the images it produces are not only particularly pleasant for observers but also improve the following steps of object localization and segmentation. Moreover, ACE can be easily implemented though parallel, optimized computation is advisable due to its high computational costs. Nevertheless, during years of applications, ACE demonstrated promising

results among all the SCAs so that some optimized implementations have been developed, which also perform automatic parameters tuning. From this analysis, we have found a growing interest of the scientific community in ACE algorithm and, in general, toward the usage of SCAs. Thanks to this work, it has been possible to better understand the directions in which the application of ACE is in course of development. Furthermore, the main advantages in the use of this algorithm have been underlined, together with its limits and needs. Starting from this study, we hope that the research in the field of SCAs will continue in the future and that the fields of colorimetry and image enhancement will develop new spatial models and algorithms able to deal with complex scenes in a global and local approach.

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References

1. A. Rizzi, C. Gatta, and D. Marini, "A new algorithm for unsupervised global and local color correction," *Pattern Recognit. Lett.* **24**(11), 1663–1677 (2003).
2. A. Rizzi, C. Gatta, and D. Marini, "From Retinex to automatic color equalization: issues in developing a new algorithm for unsupervised color equalization," *J. Electron. Imaging* **13**(1), 75–84 (2004).
3. C. Gatta, A. Rizzi, and D. Marini, "ACE: an automatic color equalization algorithm," in *Conf. Colour Graphics, Imaging, and Vision*, Society for Imaging Science and Technology, pp. 316–320 (2002).
4. A. Rizzi and J. J. McCann, "On the behavior of spatial models of color," *Proc. SPIE* **6493**, 649302 (2007).
5. E. H. Land, "The Retinex," *Am. Sci.* **52**(2), 247–264 (1964).
6. E. H. Land and J. J. McCann, "Lightness and Retinex theory," *J. Opt. Soc. Am.* **61**(1), 1–11 (1971).
7. Y. P. Loh and C. S. Chan, "Getting to know low-light images with the exclusively dark dataset," *Comput. Vision Image Understanding* **178**, 30–42 (2019).
8. D. Mould and P. L. Rosin, "A benchmark image set for evaluating stylization," in *Proc. Joint Symp. Comput. Aesthetics and Sketch Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering*, pp. 11–20 (2016).
9. A. Rizzi, D. Fogli, and B. R. Barricelli, "A new approach to perceptual assessment of human-computer interfaces," *Multimedia Tools Appl.* **76**(5), 7381–7399 (2017).
10. C. Parraman and A. Rizzi, "User preferences in colour enhancement for unsupervised printing methods," *Proc. SPIE* **6493**, 64930U (2007).
11. C. Parraman and A. Rizzi, "Searching user preferences in printing: a proposal for an automatic solution," *Printing Technology SpB06* (2006).
12. G. Ciocca et al., "Retinex preprocessing of uncalibrated images for color based image retrieval," *J. Electron. Imaging* **12**(1), 161–172 (2003).
13. Z. Munn et al., "Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach," *BMC Med. Res. Methodol.* **18**(1), 143 (2018).
14. M. D. Peters et al., "Guidance for conducting systematic scoping reviews," *Int. J. Evid.-Based Healthcare* **13**(3), 141–146 (2015).
15. H. Arksey and L. O'Malley, "Scoping studies: towards a methodological framework," *Int. J. Social Res. Methodol.* **8**(1), 19–32 (2005).
16. A.-W. Harzing, "Publish or Perish," <https://harzing.com/resources/publish-or-perish> (accessed 19 April 2021).
17. A. Rizzi et al., "Un algoritmo per la valutazione percettiva delle interfacce visuali," *DDD Disegno e Design Digitale* **7**(2), 98–106 (2003).
18. A. Rizzi et al., "Automatic lightness and color adjustment of visual interfaces," *HCI, Italy* (2003).

19. M. Chambah et al., "Perceptual approach for unsupervised digital color restoration of cinematographic archives," *Proc. SPIE* **5008**, 138–149 (2003).
20. J. J. McCann and A. Rizzi, "The spatial properties of contrast," in *Color and Imaging Conf.*, Society for Imaging Science and Technology, pp. 51–58 (2003).
21. A. Rizzi, C. Gatta, and D. Marini, "YACCD: yet another color constancy database," *Proc. SPIE* **5008**, 24–35 (2003).
22. L. Meylan and S. Susstrunk, "Bio-inspired color image enhancement," *Proc. SPIE* **5292**, 46–56 (2004).
23. L. Meylan and S. Susstrunk, "Color image enhancement using a Retinex-based adaptive filter," in *Conf. Colour Graphics, Imaging, and Vision*, Society for Imaging Science and Technology, pp. 359–363 (2004).
24. D. Marini, A. Rizzi, and M. Rossi, "Postfiltering for color appearance in synthetic image visualization," *J. Electron. Imaging* **13**(1), 111–120 (2004).
25. A. Rizzi et al., "Tuning of perceptual technique for digital movie color restoration," *Proc. SPIE* **5308**, 1286–1294 (2004).
26. L. Tao and V. K. Asari, "Adaptive and integrated neighborhood-dependent approach for nonlinear enhancement of color images," *J. Electron. Imaging* **14**(4), 043006 (2005).
27. E. Provenzi et al., "Mathematical definition and analysis of the Retinex algorithm," *J. Opt. Soc. Am. A* **22**(12), 2613–2621 (2005).
28. B. Stahre et al., "Towards perceptual colour for virtual environments," in *Proc. 10th Cong. Int. Colour Assoc. AIC Colour*, Vol. 5, pp. 8–13 (2005).
29. J. J. McCann, "Rendering high-dynamic range images: algorithms that mimic human vision," in *Proc. AMOS Tech. Conf.*, pp. 19–28 (2005).
30. C. Slanzi and A. Rizzi, "Restauro digitale del colore nelle pellicole cinematografiche: il caso de 'la ciudad en la playa'," in *Prima Conf. nazionale del Gruppo del Colore*, Pescara (2005).
31. Y. Liu et al., "A multi-scale Retinex algorithm for image enhancement," in *IEEE Int. Conf. Veh. Electron. and Safety*, IEEE, pp. 131–133 (2005).
32. A. Rizzi et al., "Unsupervised color film restoration using adaptive color equalization," *Lect. Notes Comput. Sci.* **3736**, 1–12 (2005).
33. A. Ukovich, G. Impoco, and G. Ramponi, "A tool based on the co-occurrence matrix to measure the performance of dynamic range reduction algorithms," in *IEEE Int. Workshop Imaging Syst. and Tech.*, IEEE, pp. 36–41 (2005).
34. G. Impoco, S. Marsi, and G. Ramponi, "Adaptive reduction of the dynamics of HDR video sequences," in *IEEE Int. Conf. Image Process.*, IEEE, Vol. 1, pp. I–945 (2005).
35. L. Meylan and S. Susstrunk, "High dynamic range image rendering with a Retinex-based adaptive filter," *IEEE Trans. Image Process.* **15**(9), 2820–2830 (2006).
36. V. Agarwal et al., "An overview of color constancy algorithms," *J. Pattern Recognit. Res.* **1**(1), 42–54 (2006).
37. A. Artusi et al., "Speed-up technique for a local automatic colour equalization model," *Comput. Graph. Forum* **25**(1), 5–14 (2006).
38. A. Rizzi, D. Gadia, and D. Marini, "Analysis of tristimulus interdependence and contextual color correction," *J. Electron. Imaging* **15**(4), 041202 (2006).
39. R. Lam, J. Rodrigues, and J. Du Buf, "Looking through the eyes of the painter: from visual perception to non-photorealistic rendering," in *14th Int. Conf. Central Eur. Comput. Graphics, Visualization and Comput. Vision*, Václav Skala-UNION Agency, pp. 147–154 (2006).
40. S. Nunes et al., "Perception-based painterly rendering: functionality and interface design," in *Ibero-Am. Symp. Comput. Graphics*, P. Brunet, N. Correia, and G. Baranoski, Eds., The Eurographics Association (2006).
41. M. Chambah, "More than color constancy: nonuniform color cast correction techniques and applications," in *Computer Vision and Graphics*, K. Wojciechowski et al., Eds., pp. 780–786, Springer, Dordrecht (2006).
42. L. Tao, M.-J. Seow, and V. K. Asari, "Nonlinear image enhancement to improve face detection in complex lighting environment," *Proc. SPIE* **6064**, 606416 (2006).
43. R. A. Palma-Amestoy et al., "Context-dependent color segmentation for Aibo robots," in *IEEE 3rd Latin Am. Rob. Symp.*, IEEE, pp. 128–136 (2006).

44. D. Keysers, C. H. Lampert, and T. M. Breuel, "Color image dequantization by constrained diffusion," *Proc. SPIE* **6058**, 605803 (2006).
45. R. A. Palma-Amestoy et al., "Context-dependent color segmentation for Aibo robots," in *IEEE 3rd Latin Am. Rob. Symp.*, IEEE, pp. 128–136 (2006).
46. J. McCann and A. Rizzi, "Invited talk: spatial comparisons: the antidote to veiling glare limitations in HDR images," in *Proc. Third Am. Display Eng. and Appl. Conf.*, pp. 155–158 (2006).
47. C. Gatta, A. Rizzi, and D. Marini, "Local linear LUT method for spatial colour-correction algorithm speed-up," *IEE Proc. Vision Image Signal Process.* **153**(3), 357–363 (2006).
48. L. Tao and V. K. Asari, "An efficient illuminance-reflectance nonlinear video stream enhancement model," *Proc. SPIE* **6063**, 60630I (2006).
49. D. Alleysson, L. Meylan, and S. Süsstrunk, "HDR CFA image rendering," in *14th Eur. Signal Process. Conf.*, IEEE, pp. 1–4 (2006).
50. J. J. McCann, "Art, science, and appearance in HDR," *J. Soc. Inf. Disp.* **15**(9), 709–719 (2007).
51. C. Gatta, A. Rizzi, and D. Marini, "Perceptually inspired HDR images tone mapping with color correction," *Int. J. Imaging Syst. Technol.* **17**(5), 285–294 (2007).
52. M. Bertalmío et al., "Perceptual color correction through variational techniques," *IEEE Trans. Image Process.* **16**(4), 1058–1072 (2007).
53. J. Rodrigues and J. du Buf, "Image morphology: from perception to rendering," *Image-J. Interdiscip. Image Sci.* **5**, 1–19 (2007).
54. L. Lei, Y. Zhou, and J. Li, "An investigation of Retinex algorithms for image enhancement," *J. Electron.* **24**(5), 696–700 (2007).
55. J. J. McCann and A. Rizzi, "Camera and visual veiling glare in HDR images," *J. Soc. Inf. Disp.* **15**(9), 721–730 (2007).
56. E. Provenzi et al., "Random spray Retinex: a new Retinex implementation to investigate the local properties of the model," *IEEE Trans. Image Process.* **16**(1), 162–171 (2007).
57. S. Shah, "Image enhancement for increased dot-counting efficiency in fish," *J. Microsc.* **228**(2), 211–226 (2007).
58. S. Marsi et al., "Video enhancement and dynamic range control of HDR sequences for automotive applications," *EURASIP J. Adv. Signal Process.* **2007**, 1–9 (2007).
59. J. J. McCann and A. Rizzi, "Spatial comparisons: the antidote to veiling glare limitations in image capture and display," in *Proc. IMQA* (2007).
60. R. Schettini et al., "Integrating imaging and vision for content-specific image enhancement," in *2nd Int. Conf. Comput. Vision Theory and Appl.*, pp. 192–199 (2007).
61. A. Rizzi, "Human visual perception and spatial models of colour," in *Collaborate-Innovate-Create-Managing Colour in Digital Processes and the Arts (CREATE)*, Citeseer (2007).
62. G. Ciocca et al., "Content aware image enhancement," *Lect. Notes Comput. Sci.* **4733**, 686–697 (2007).
63. V. Vonikakis and I. Andreadis, "Fast automatic compensation of under/over-exposed image regions," *Lect. Notes Comput. Sci.* **4872**, 510–521 (2007).
64. M. Chambah, A. Rizzi, and C. S. Jean, "Image quality and automatic color equalization," *Proc. SPIE* **6494**, 64940B (2007).
65. G. Ciocca et al., "Integrating imaging and vision for content-specific image enhancement," in *Proc. Second Int. Conf. Comput. Vision Theory and Appl.*, INSTICC, SciTePress, Vol. 2, pp. 192–199 (2007).
66. J. J. McCann and A. Rizzi, "Veiling glare: the dynamic range limit of HDR images," *Proc. SPIE* **6492**, 649213 (2007).
67. J. M. F. Rodrigues, "Integrated multi-scale architecture of the cortex with application to computer vision," PhD Thesis, Universidade do Algarve (2007).
68. A. Ukovich, "Image processing for security applications: document reconstruction and video enhancement," PhD Thesis, Università degli Studi di Trieste (2007).
69. J. Y. Hardeberg, E. Bando, and M. Pedersen, "Evaluating colour image difference metrics for gamut-mapped images," *Color. Technol.* **124**(4), 243–253 (2008).

70. E. Provenzi et al., “A spatially variant white-patch and gray-world method for color image enhancement driven by local contrast,” *IEEE Trans. Pattern Anal. Mach. Intell.* **30**(10), 1757–1770 (2008).
71. V. Vonikakis, I. Andreadis, and A. Gasteratos, “Fast centre-surround contrast modification,” *IET Image Process.* **2**(1), 19–34 (2008).
72. S. Marsi et al., “Using a recursive rational filter to enhance color images,” *IEEE Trans. Instrum. Meas.* **57**(6), 1230–1236 (2008).
73. A. Rizzi et al., “A mixed perceptual and physical-chemical approach for the restoration of faded positive films,” in *Conf. Colour Graphics, Imaging, and Vision*, Society for Imaging Science and Technology, pp. 292–295 (2008).
74. D. Gadia et al., “Color management and color perception issues in a virtual reality theater,” *Proc. SPIE* **6803**, 68030S (2008).
75. S. Ouni et al., “DAF: differential ace filtering image quality assessment by automatic color equalization,” *Proc. SPIE* **6808**, 68080W (2008).
76. V. Vonikakis and I. Andreadis, “Multi-scale image contrast enhancement,” in *10th Int. Conf. Control, Autom., Rob. and Vision*, IEEE, pp. 856–861 (2008).
77. S. Ouni et al., “Are existing procedures enough? Image and video quality assessment: review of subjective and objective metrics,” *Proc. SPIE* **6808**, 68080Q (2008).
78. N. Unaldi, V. K. Asari, and Z.-U. Rahman, “Fast and robust wavelet-based dynamic range compression with local contrast enhancement,” *Proc. SPIE* **6978**, 697805 (2008).
79. R. Palma-Amestoy et al., “A perceptually inspired variational framework for color enhancement,” *IEEE Trans. Pattern Anal. Mach. Intell.* **31**(3), 458–474 (2009).
80. H. Han and K. Sohn, “Automatic illumination and color compensation using mean shift and sigma filter,” *IEEE Trans. Consum. Electron.* **55**(3), 978–986 (2009).
81. M. Bertalmío, V. Caselles, and E. Provenzi, “Issues about Retinex theory and contrast enhancement,” *Int. J. Comput. Vision* **83**, 101–119 (2009).
82. M. Bertalmío and J. D. Cowan, “Implementing the Retinex algorithm with Wilson–Cowan equations,” *J. Physiol.-Paris* **103**(1-2), 69–72 (2009).
83. B. Stahre, M. Billger, and K. F. Anter, “To colour the virtual world: difficulties in visualizing spatial colour appearance in virtual environments,” *Int. J. Archit. Comput.* **7**(2), 289–308 (2009).
84. J. Demongeot et al., “Understanding physiological and degenerative natural vision mechanisms to define contrast and contour operators,” *PLoS One* **4**(6), e6010 (2009).
85. G. Schaefer et al., “Skin lesion extraction in dermoscopic images based on colour enhancement and iterative segmentation,” in *16th IEEE Int. Conf. Image Process.*, pp. 3361–3364 (2009).
86. G. Schaefer et al., “Skin lesion segmentation using co-operative neural network edge detection and colour normalisation,” in *9th Int. Conf. Inf. Technol. and Appl. Biomed.*, pp. 1–4 (2009).
87. N. Desai et al., “A fuzzy logic based approach to de-weather fog-degraded images,” in *Sixth Int. Conf. Comput. Graphics, Imaging and Visualization*, pp. 383–387 (2009).
88. H. Han and K. Sohn, “HVS-aware ROI-based illumination and color restoration,” in *16th IEEE Int. Conf. Image Process.*, IEEE, pp. 3921–3924 (2009).
89. H. Han and K. Sohn, “Human perception inspired exposure correction using total variation model,” in *TENCON IEEE Region 10 Conf.*, IEEE, pp. 1–6 (2009).
90. S. Ouni et al., “SCID: full reference spatial color image quality metric,” *Proc. SPIE* **7242**, 72420U (2009).
91. M. Lecca and S. Messelodi, “Illuminant change estimation via minimization of color histogram divergence,” *Lect. Notes Comput. Sci.* **5646**, 41–50 (2009).
92. C. Bonanomi et al., “Computazione dell’apparenza visiva di manifesti pubblicitari,” in *Conf. Nazionale del Gruppo del Colore*, Starrylink editrice (2009).
93. S. Zuffi et al., “A study on the equivalence of controlled and uncontrolled visual experiments,” *Proc. SPIE* **7241**, 724102 (2009).
94. H. Yu, J. Wang, and H.-R. Yin, “Color cast removal based on fitting gray-axis,” in *Int. Conf. Mach. Learn. and Cybern.*, IEEE, Vol. 4, pp. 2394–2397 (2009).

95. K.-D. Lee, S. Kim, and S.-D. Kim, "Dynamic range compression based on statistical analysis," in *16th IEEE Int. Conf. Image Process.*, IEEE, pp. 3157–3160 (2009).
96. E. Provenzi, "Perceptual color correction: a variational perspective," *Lect. Notes Comput. Sci.* **5646**, 109–119 (2009).
97. X. Petrova, S. Sedunov, and A. Ignatov, "Unsupervised exposure correction for video," *Proc. SPIE* **7244**, 72440N (2009).
98. M. Fierro, H.-G. Ha, and Y.-H. Ha, "An automatic color correction method inspired by the Retinex and opponent colors theories," in *Int. Symp. Optomechatron. Technol.*, IEEE, pp. 316–321 (2009).
99. N. Unaldi, V. K. Asari, and Z.-U. Rahman, "Fast and robust wavelet-based dynamic range compression and contrast enhancement model with color restoration," *Proc. SPIE* **7341**, 734111 (2009).
100. J.-M. Morel, A. B. Petro, and C. Sbert, "Fast implementation of color constancy algorithms," *Proc. SPIE* **7241**, 724106 (2009).
101. C. S. T. Madden, "Tracking people across disjoint camera views," PhD Thesis, Faculty of Information Technology, University of Technology, Sydney (UTS) (2009).
102. A. Choudhury and G. Medioni, "Perceptually motivated automatic color contrast enhancement based on color constancy estimation," *EURASIP J. Image Video Process.* **2010**, 1–22 (2010).
103. R. Schettini and S. Corchs, "Underwater image processing: state of the art of restoration and image enhancement methods," *EURASIP J. Adv. Signal Process.* **2010**, 1–14 (2010).
104. S. Zuffi et al., "Comparing image preference in controlled and uncontrolled viewing conditions," *J. Electron. Imaging* **19**(4), 043014 (2010).
105. A. Capra et al., "A contrast image correction method," *J. Electron. Imaging* **19**(2), 023005 (2010).
106. A. Rizzi and C. Parraman, "Developments in the recovery of colour in fine art prints using spatial image processing," *J. Phys. Conf. Ser.* **231**(1), 012003 (2010).
107. A. Rizzi and M. Chambah, "Perceptual color film restoration," *SMPTE Motion Imaging J.* **119**(8), 33–41 (2010).
108. A. T. Islam and I. Farup, "Enhancing the output of spatial color algorithms," in *2nd Eur. Workshop Visual Inf. Process.*, IEEE, pp. 7–12 (2010).
109. C. Hsin et al., "Improving image luminance appearance through recurrent local intensity adaptation," in *2nd Int. Conf. Signal Processing Systems*, IEEE, Vol. 2, pp. V2–31 (2010).
110. K. Iqbal et al., "Enhancing the low quality images using unsupervised colour correction method," in *IEEE Int. Conf. Syst., Man and Cybern.*, IEEE, pp. 1703–1709 (2010).
111. D. Gadia et al., "Local color correction of stereo pairs," *Proc. SPIE* **7524**, 75240W (2010).
112. S. Naji, R. Zainuddin, and J. Al-Jaafar, "Automatic illumination correction for human skin," in *Int. Conf. Intell. Network and Comput.*, Kuala Lumpur, Malaysia (2010).
113. J. Zhang et al., "Progressive image color neutralization based on adaptive histogram clustering," in *Fifth Int. Conf. Image and Graphics*, IEEE, pp. 113–118 (2009).
114. J. Wang and H. Bi, "Retinex-based color correction for displaying high dynamic range images," in *IEEE 10th Int. Conf. Signal Process. Proc.*, pp. 1021–1024 (2010).
115. C. Parraman and A. Rizzi, "Spatial image processing for the enhancement and restoration of film, photography and print," in *7th Int. Conf. Inf. and Syst.*, pp. 1–8 (2010).
116. C. Prabhakar and P. P. Kumar, "Underwater image denoising using adaptive wavelet sub-band thresholding," in *Int. Conf. Signal and Image Process.*, IEEE, pp. 322–327 (2010).
117. G. Schaefer et al., "Colour and contrast enhancement for improved skin lesion segmentation," *Comput. Med. Imaging Graph.* **35**(2), 99–104 (2011).
118. C.-Y. Tsai and C.-H. Chou, "A novel simultaneous dynamic range compression and local contrast enhancement algorithm for digital video cameras," *EURASIP J. Image Video Process.* **2011**(1), 6 (2011).
119. J. Majumdar, M. Nandi, and P. Nagabhushan, "Retinex algorithm with reduced halo artifacts," *Def. Sci. J.* **61**, 559–566 (2011).
120. Ø. Kolås, I. Farup, and A. Rizzi, "Spatio-temporal Retinex-inspired envelope with stochastic sampling: a framework for spatial color algorithms," *J. Imaging Sci. Technol.* **55**(4), 040503 (2011).

121. H. P. Barreto and I. R. T. Villalobos, "Contrast enhancement based on a morphological rational multiscale algorithm," *Rev. Comput. Sistemas* **14**(3), 253–267 (2011).
122. F. Shao et al., "A perception-based color correction method for multi-view images," *KSII Trans. Internet Inf. Syst.* **5**(2), 390–407 (2011).
123. H. Peregrina-Barreto et al., "Morphological rational operator for contrast enhancement," *J. Opt. Soc. Am. A* **28**(3), 455–464 (2011).
124. H. Shin et al., "Rendering high dynamic range images by using integrated global and local processing," *Opt. Eng.* **50**(11), 117002 (2011).
125. A. T. Islam and I. Farup, "Spatio-temporal colour correction of strongly degraded movies," *Proc. SPIE* **7866**, 78660Z (2011).
126. P. Zhang and C. Li, "Region-based color image segmentation of fishes with complex background in water," in *IEEE Int. Conf. Comput. Sci. and Autom. Eng.*, IEEE, Vol. 1, pp. 596–600 (2011).
127. W. Yin, X. Lin, and Y. Sun, "A novel framework for low-light colour image enhancement and denoising," in *3rd Int. Conf. Awareness Sci. and Technol.*, IEEE, pp. 20–23 (2011).
128. Z. Feng, X. Zhang, and J. Zhang, "Fusion of multispectral and panchromatic images using IHS transform and ACE model," in *Int. Conf. Control, Autom. and Syst. Eng.*, IEEE, pp. 1–4 (2011).
129. H.-Y. Yang et al., "Low complexity underwater image enhancement based on dark channel prior," in *Second Int. Conf. Innovations Bio-Inspired Comput. and Appl.*, IEEE, pp. 17–20 (2011).
130. N. M. Kwok et al., "Gray world based color correction and intensity preservation for image enhancement," in *4th Int. Cong. Image and Signal Process.*, IEEE, Vol. 2, pp. 994–998 (2011).
131. S. Xie and J. Pan, "Hand detection using robust color correction and Gaussian mixture model," in *Sixth Int. Conf. Image and Graphics*, IEEE, pp. 553–557 (2011).
132. L. Wong and K. Low, "Saliency retargeting: an approach to enhance image aesthetics," in *IEEE Workshop Appl. Comput. Vision*, pp. 73–80 (2011).
133. Y.-K. Wang and W.-B. Huang, "Acceleration of the Retinex algorithm for image restoration by GPGPU/CUDA," *Proc. SPIE* **7872**, 78720E (2011).
134. P. Getreuer, "Automatic color enhancement (ACE) and its fast implementation," *Image Process. On Line* **2**, 266–277 (2012).
135. H. Li, L. Zhang, and H. Shen, "A perceptually inspired variational method for the uneven intensity correction of remote sensing images," *IEEE Trans. Geosci. Remote Sens.* **50**(8), 3053–3065 (2012).
136. N. Mittal, "Automatic contrast enhancement of low contrast images using MATLAB," *Int. J. Adv. Res. Comput. Sci.* **3**(1), 3053–3065 (2012).
137. Y. Wang and Y. Luo, "Balanced color contrast enhancement for digital images," *Opt. Eng.* **51**(10), 107001 (2012).
138. H. Peregrina-Barreto et al., "Corrección cromática aplicada a imágenes de exteriores," *Comput. Sistemas* **16**(1), 85–97 (2012).
139. H. Peregrina-Barreto et al., "Chromatic correction applied to outdoor images," *Comput. Sistemas* **16**(1), 85–97 (2012).
140. J. E. R. de Queiroz et al., "Non-photorealistic neural sketching," *J. Braz. Comput. Soc.* **18**(3), 237 (2012).
141. N. A. M. Isa et al., "Pixel distribution shifting color correction for digital color images," *Appl. Soft Comput.* **12**(9), 2948–2962 (2012).
142. E. Roe and C. A. Mello, "Automatic system for restoring old color postcards," in *IEEE Int. Conf. Syst., Man, and Cybern.*, IEEE, pp. 451–456 (2012).
143. A. Mahiddine et al., "Underwater image preprocessing for automated photogrammetry in high turbidity water: an application on the Arles-Rhone XIII Roman Wreck in the Rhodano River, France," in *18th Int. Conf. Virtual Syst. and Multimedia*, IEEE, pp. 189–194 (2012).
144. A. Mahiddine et al., "Performances analysis of underwater image preprocessing techniques on the repeatability of SIFT and SURF descriptors," in *20th Int. Conf. Comput. Graphics, Visualization and Comput. Vision* (2012).

145. N. bt Shamsuddin et al., "Significance level of image enhancement techniques for underwater images," in *Int. Conf. Comput. and Inf. Sci.*, IEEE, Vol. 1, pp. 490–494 (2012).
146. G. Simone et al., "Termites: a Retinex implementation based on a colony of agents," *Proc. SPIE* **8292**, 82920N (2012).
147. W. L. Kuan, "Saliency-based image enhancement," PhD Thesis, School of Computing, National University of Singapore (2012).
148. A. Rizzi and C. Bonanomi, "Colour illusions and the human visual system," in *Colour Design*, J. Best, Ed., pp. 83–104, Woodhead Publishing (2012).
149. N. Banić and S. Lončarić, "Light random sprays Retinex: exploiting the noisy illumination estimation," *IEEE Signal Process. Lett.* **20**(12), 1240–1243 (2013).
150. N. M. Kwok et al., "Simultaneous image color correction and enhancement using particle swarm optimization," *Eng. Appl. Artif. Intell.* **26**(10), 2356–2371 (2013).
151. M. Fierro, H.-G. Ha, and Y.-H. Ha, "Noise reduction based on partial-reference, dual-tree complex wavelet transform shrinkage," *IEEE Trans. Image Process.* **22**(5), 1859–1872 (2013).
152. K. B. Gibson and T. Q. Nguyen, "A no-reference perceptual based contrast enhancement metric for ocean scenes in fog," *IEEE Trans. Image Process.* **22**(10), 3982–3993 (2013).
153. H. J. Tang, "Color calibration method for printing and dyeing manufacturers," *Appl. Mech. Mater.* **310**, 258–261 (2013).
154. W.-J. Kyung et al., "Correction of faded colors in an image using an integrated multi-scale gray world algorithm," *J. Imaging Sci. Technol.* **57**(6), 605051 (2013).
155. Y. Mahech, B. S. Babu, and A. S. Nageswararao, "Automatic wavelet-based nonlinear image enhancement for aerial imagery," *J. Appl. Sci. Eng.* **19**(3), 357–370 (2016).
156. R. Benenson et al., "Seeking the strongest rigid detector," in *IEEE Conf. Comput. Vision and Pattern Recognit.*, pp. 3666–3673 (2013).
157. H. Lu, Y. Li, and S. Serikawa, "Underwater image enhancement using guided trigonometric bilateral filter and fast automatic color correction," in *IEEE Int. Conf. Image Process.*, IEEE, pp. 3412–3416 (2013).
158. H. Lu et al., "Underwater optical image enhancement using guided trigonometric bilateral filtering and colorization," in *Proc. IEEE Int. Symp. Underwater Technol.*, pp. 1–6 (2013).
159. D. Zosso, G. Tran, and S. Osher, "A unifying retinex model based on non-local differential operators," *Proc. SPIE* **8657**, 865702 (2013).
160. T. Islam and O. Staadt, "Bandwidth-efficient image degradation and enhancement model for multi-camera telepresence environments," in *Proc. 10th Eur. Conf. Visual Media Production*, pp. 1–8 (2013).
161. X. Liu and J. Y. Hardeberg, "Fog removal algorithms: survey and perceptual evaluation," in *Eur. Workshop Visual Inf. Process.*, IEEE, pp. 118–123 (2013).
162. C. Mosquera-Lopez and S. Agaian, "Iterative local color normalization using fuzzy image clustering," *Proc. SPIE* **8755**, 875518 (2013).
163. B. Henke, M. Vahl, and Z. Zhou, "Removing color cast of underwater images through non-constant color constancy hypothesis," in *8th Int. Symp. Image and Signal Process. and Anal.*, IEEE, pp. 20–24 (2013).
164. Y.-J. Chen et al., "The non-linear logarithm method (NLLM) to adjust the color deviation of fluorescent images," *Proc. SPIE* **8769**, 87693E (2013).
165. K. B. Gibson, "The color ellipsoid framework for imaging in the atmosphere," PhD Thesis, UC San Diego (2013).
166. A. Tsitiridis, "Biologically-inspired machine vision," PhD Thesis, Cranfield University (2013).
167. J.-M. Morel, A.-B. Petro, and C. Sbert, "Screened Poisson equation for image contrast enhancement," *Image Process. On Line* **4**, 16–29 (2014).
168. L. Wang et al., "Variational Bayesian method for retinex," *IEEE Trans. Image Process.* **23**(8), 3381–3396 (2014).
169. M. Nikolova and G. Steidl, "Fast hue and range preserving histogram specification: theory and new algorithms for color image enhancement," *IEEE Trans. Image Process.* **23**(9), 4087–4100 (2014).
170. M. Bertalmío, "From image processing to computational neuroscience: a neural model based on histogram equalization," *Front. Comput. Neurosci.* **8**, 71 (2014).

171. H. Lu, Y. Li, and X. Hu, "Underwater scene reconstruction via image pre-processing," *J. Comput. Consum. Control* **3**(4), 37–45 (2014).
172. L. Chen, W. Sun, and J. Feng, "A fast image enhancement algorithm using bright channel," in *Intelligent Data analysis and its Applications*, J. S. Pan et al., Eds., Vol. II, pp. 565–574, Springer, Cham (2014).
173. E. Provenzi and V. Caselles, "A wavelet perspective on variational perceptually-inspired color enhancement," *Int. J. Comput. Vision* **106**(2), 153–171 (2014).
174. S. W. Zamir et al., "Gamut mapping in cinematography through perceptually-based contrast modification," *IEEE J. Sel. Top. Signal Process.* **8**(3), 490–503 (2014).
175. G. Gianini, A. Manenti, and A. Rizzi, "QBRIX: a quantile-based approach to retinex," *J. Opt. Soc. Am. A* **31**(12), 2663–2673 (2014).
176. J. J. McCann, C. Parraman, and A. Rizzi, "Reflectance, illumination, and appearance in color constancy," *Front. Psychol.* **5**, 5 (2014).
177. Z. Chen et al., "Region-specialized underwater image restoration in inhomogeneous optical environments," *Optik* **125**(9), 2090–2098 (2014).
178. A. S. A. Ghani and N. A. M. Isa, "Underwater image quality enhancement through composition of dual-intensity images and Rayleigh-stretching," *Springerplus* **3**(1), 757 (2014).
179. A. S. A. Ghani and N. A. M. Isa, "Underwater image quality enhancement through Rayleigh-stretching and averaging image planes," *Int. J. Nav. Archit. Ocean Eng.* **6**(4), 840–866 (2014).
180. Y.-K. Wang and W.-B. Huang, "A CUDA-enabled parallel algorithm for accelerating Retinex," *J. Real-Time Image Process.* **9**(3), 407–425 (2014).
181. G. Simone et al., "Termite Retinex: a new implementation based on a colony of intelligent agents," *J. Electron. Imaging* **23**(1), 013006 (2014).
182. J.-M. Morel, A. B. Petro, and C. Sbert, "What is the right center/surround for Retinex?" in *IEEE Int. Conf. Image Process.*, IEEE, pp. 4552–4556 (2014).
183. S. Paisitkriangkrai, C. Shen, and A. Van Den Hengel, "Strengthening the effectiveness of pedestrian detection with spatially pooled features," *Lect. Notes Comput. Sci.* **8692**, 546–561 (2014).
184. M. Mathias et al., "Face detection without bells and whistles," *Lect. Notes Comput. Sci.* **8692**, 720–735 (2014).
185. J. Osterloff et al., "Ranking color correction algorithms using cluster indices," in *ICPR Workshop Comput. Vision Anal. Underwater Imagery*, IEEE, pp. 41–48 (2014).
186. J. T. Simon-Liedtke et al., "Pixel-wise illuminant estimation for mixed illuminant scenes based on near-infrared camera information," in *22nd Color and Imaging Conf. Final Program and Proc.*, Society for Imaging Science and Technology, pp. 217–221 (2014).
187. P. Drap et al., "Underwater multimodal survey: merging optical and acoustic data," in *Underwater Seascapes*, O. Musard et al., Eds., pp. 221–238, Springer, Cham (2014).
188. N. Banić and S. Lončarić, "Smart light random memory sprays Retinex: a fast Retinex implementation for high-quality brightness adjustment and color correction," *J. Opt. Soc. Am. A* **32**(11), 2136–2147 (2015).
189. A. S. A. Ghani and N. A. M. Isa, "Underwater image quality enhancement through integrated color model with Rayleigh distribution," *Appl. Soft Comput.* **27**, 219–230 (2015).
190. D. Zosso, G. Tran, and S. J. Osher, "Non-local Retinex: a unifying framework and beyond," *SIAM J. Imaging Sci.* **8**(2), 787–826 (2015).
191. S. Ferradans, R. Palma-Amestoy, and E. Provenzi, "An algorithmic analysis of variational models for perceptual local contrast enhancement," *Image Process. On Line* **5**, 219–233 (2015).
192. S. W. Zamir, J. Vazquez-Corral, and M. Bertalmío, "Gamut extension for cinema: psycho-physical evaluation of the state of the art and a new algorithm," *Proc. SPIE* **9394**, 93940U (2015).
193. R. Sharma and A. Shelotkar, "Advance underwater image reconstruction using un-sharp masking and AFSMF: a review," *Int. J. Sci. Eng. Res.* **6**(5), 689 (2015).
194. M. Gargano, D. Bertani, and M. Greco et al., "A perceptual approach to the fusion of visible and NIR images in the examination of ancient documents," *J. Cult. Heritage* **16**(4), 518–525 (2015).

195. M. Celebi et al., "A state-of-the-art survey on lesion border detection in dermoscopy images," in *Dermoscopy Image Analysis*, M. E. Celebi, T. Mendonca, and J. S. Marques, Eds., pp. 97–129, CRC Press, Boca Raton (2015).
196. C. Xia et al., "Automatic identification and counting of small size pests in greenhouse conditions with low computational cost," *Ecol. Inf.* **29**, 139–146 (2015).
197. A. Galdran et al., "Enhanced variational image dehazing," *SIAM J. Imaging Sci.* **8**(3), 1519–1546 (2015).
198. A. S. A. Ghani and N. A. M. Isa, "Enhancement of low quality underwater image through integrated global and local contrast correction," *Appl. Soft Comput.* **37**, 332–344 (2015).
199. L. Wang et al., "Local brightness adaptive image colour enhancement with Wasserstein distance," *IET Image Process.* **9**(1), 43–53 (2015).
200. A. Gambaruto, "Processing the image gradient field using a topographic primal sketch approach," *Int. J. Num. Methods Biomed. Eng.* **31**(3), e02706 (2015).
201. E. Roe and C. A. B. de Mello, "Restoring images of ancient color postcards," *Visual Comput.* **31**(5), 627–641 (2015).
202. M. Lecca and A. Rizzi, "Tuning the locality of filtering with a spatially weighted implementation of random spray Retinex," *J. Opt. Soc. Am. A* **32**(10), 1876–1887 (2015).
203. J. G. Chongyi Li, "Underwater image enhancement by dehazing and color correction," *J. Electron. Imaging* **24**, 033023 (2015).
204. A. AbuNaser et al., "Underwater image enhancement using particle swarm optimization," *J. Intell. Syst.* **24**(1), 99–115 (2015).
205. M. Dehesa et al., "Chromatic improvement of backgrounds images captured with environmental pollution using Retinex model," *Res. Comput. Sci.* **102**, 33–40 (2015).
206. E. Y. Smirnova, E. A. Chizhkova, and A. V. Chizhov, "A mathematical model of color and orientation processing in v1," *Biol. Cybern.* **109**(4-5), 537–547 (2015).
207. Z. Dai, X. Wang, and J. Yang, "Approach to sunflicker removal for underwater image," *J. Electron. Imaging* **24**(6), 061206 (2015).
208. N. Banić and S. Lončarić, "Firefly: a hardware-friendly real-time local brightness adjustment method," in *IEEE Int. Conf. Image Process.*, IEEE, pp. 3951–3955 (2015).
209. J. H. Fitschen et al., "A variational model for color assignment," *Lect. Notes Comput. Sci.* **9087**, 437–448 (2015).
210. Y. Wang et al., "Mobile image based color correction using deblurring," *Proc. SPIE* **9401**, 940107 (2015).
211. Y. Yang, Z. Wang, and F. Wu, "Exploring prior knowledge for pedestrian detection," in *Proc. Br. Mach. Vision Conf.*, BMVA Press, pp. 176.1–176.12 (2015).
212. P. Cyriac et al., "A tone mapping operator based on neural and psychophysical models of visual perception," *Proc. SPIE* **9394**, 93941I (2015).
213. A. Galdran et al., "A variational framework for single image dehazing," *Lect. Notes Comput. Sci.* **8927**, 259–270 (2014).
214. V. W. De Dravo and J. Y. Hardeberg, "Stress for dehazing," in *Colour and Visual Comput. Symp.*, IEEE, pp. 1–6 (2015).
215. T. Schoening, "Automated detection in benthic images for megafauna classification and marine resource exploration: supervised and unsupervised methods for classification and regression tasks in benthic images with efficient integration of expert knowledge," PhD Thesis, University of Bielefeld (2015).
216. G. T. T. Tran, "Sparsity-inducing methods in imaging sciences and partial differential equations," PhD Thesis, UCLA (2015).
217. L. Wang, L. Xiao, and Z. Wei, *Color Equalization and Retinex*, pp. 253–289, Springer, Cham (2015).
218. A. Rizzi and J. J. McCann, "Understanding glare and how it limits scene reproduction," in *Handbook of Digital Imaging*, pp. 1–26 (2015).
219. G. Simone et al., "Ant colony for locality foraging in image enhancement," in *Multi-Objective Swarm Intelligence*, S. Dehuri, A. Jagadev, and M. Panda, Eds., pp. 123–142, Springer, Berlin, Heidelberg (2015).
220. A. Alfalou and C. Brosseau, "Recent advances in optical image processing," *Prog. Opt.* **60**, 119–262 (2015).

221. L. Ye, Z. Hou, and H.-L. Eng, "Context aware image enhancement for online fish behaviour monitoring," *IET Image Process.* **10**(2), 149–157 (2016).
222. K. S. Song, H. Kang, and M. G. Kang, "Hue-preserving and saturation-improved color histogram equalization algorithm," *J. Opt. Soc. Am. A* **33**(6), 1076–1088 (2016).
223. G. Gianini, M. Lecca, and A. Rizzi, "A population-based approach to point-sampling spatial color algorithms," *J. Opt. Soc. Am. A* **33**(12), 2396–2413 (2016).
224. C.-M. Kuo et al., "An effective and flexible image enhancement algorithm in compressed domain," *Multimedia Tools Appl.* **75**(2), 1177–1200 (2016).
225. J.-L. Lisani et al., "An inquiry on contrast enhancement methods for satellite images," *IEEE Trans. Geosci. Remote Sens.* **54**(12), 7044–7054 (2016).
226. A. Rizzi, "Designator Retinex, Milano Retinex and the locality issue," *Electron. Imaging* **2016**(6), 1–5 (2016).
227. M. Lecca, A. Rizzi, and G. Gianini, "Energy-driven path search for termite Retinex," *J. Opt. Soc. Am. A* **33**(1), 31–39 (2016).
228. Z. Zhou et al., "Fusion of infrared and visible images for night-vision context enhancement," *Appl. Opt.* **55**(23), 6480–6490 (2016).
229. A. Madooei and M. S. Drew, "Incorporating colour information for computer-aided diagnosis of melanoma from dermoscopy images: a retrospective survey and critical analysis," *Int. J. Biomed. Imaging* **2016**, 1–18 (2016).
230. V. J. Whannou de Dravo and J. Y. Hardeberg, "Multiscale approach for dehazing using the stress framework," *Electron. Imaging* **2016**(20), 1–13 (2016).
231. D. Gadia et al., "Perceptual enhancement of degraded Etruscan wall paintings," *J. Cult. Heritage* **21**, 904–909 (2016).
232. D. L. Marini, C. Bonanomi, and A. Rizzi, "Processing astro-photographs using Retinex based methods," *Electron. Imaging* **2016**(6), 1–10 (2016).
233. J. Yeonan-Kim and M. Bertalmío, "Retinal lateral inhibition provides the biological basis of long-range spatial induction," *PLoS One* **11**, e0168963 (2016).
234. A. S. A. Ghani, R. S. N. A. R. Aris, and M. L. M. Zain, "Unsupervised contrast correction for underwater image quality enhancement through integrated-intensity stretched-Rayleigh histograms," *J. Telecommun. Electron. Comput. Eng.* **8**(3), 1–7 (2016).
235. A. Rizzi et al., "Unsupervised digital movie restoration with spatial models of color," *Multimedia Tools Appl.* **75**(7), 3747–3765 (2016).
236. F. B. Mohd, "Intensity adjustment analysis of underwater images," *J. Comput. Technol. Creative Content* **1**(1), 1–5 (2016).
237. R. Sethi et al., "An optimal underwater image enhancement based on fuzzy gray world algorithm and bacterial foraging algorithm," in *Fifth Natl. Conf. Comput. Vision, Pattern Recognit., Image Process. and Graphics*, IEEE, pp. 1–4 (2015).
238. D. Marini, C. Bonanomi, and A. Rizzi, "A novel approach to visual rendering of astro-photographs," *Proc. SPIE* **9913**, 99134P (2016).
239. M. Bertalmío, "Connections between Retinex, neural models and variational methods," *Electron. Imaging* **2016**(6), 1–6 (2016).
240. F. Pierre et al., "Hue-preserving perceptual contrast enhancement," in *IEEE Int. Conf. Image Process.*, IEEE, pp. 4067–4071 (2016).
241. X. Wang et al., "A fast algorithm for image defogging," *Proc. SPIE* **9684**, 968427 (2016).
242. D. G. Mario et al., "Chromaticity improvement in images with poor lighting using the multi-scale-Retinex MSR algorithm," in *9th Int. Kharkiv Symp. Phys. and Eng. Microwaves, Millimeter and Submillimeter Waves*, IEEE, pp. 1–4 (2016).
243. N. Banić and S. Lončarić, "Puma: a high-quality Retinex-based tone mapping operator," in *24th Eur. Signal Process. Conf.*, IEEE, pp. 943–947 (2016).
244. H. Liu and L.-P. Chau, "Underwater image color correction based on surface reflectance statistics," in *Asia-Pacific Signal and Inf. Process. Assoc. Annu. Summit and Conf.*, IEEE, pp. 996–999 (2015).
245. N. Unaldi, "Wavelet domain Retinex algorithm for image contrast enhancement," *Proc. SPIE* **9869**, 986907 (2016).

246. J. M. Durden et al., "Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding," in *Oceanography and Marine Biology*, pp. 9–80, CRC Press, Boca Raton (2016).
247. J.-H. Yoo et al., "Color image enhancement using weighted multi-scale compensation based on the gray world assumption," *J. Imaging Sci. Technol.* **61**(3), 305071 (2017).
248. K.-W. Liao and D.-R. Cheng, "Restoration of the distorted color to detect the discoloration status of a steel bridge coating using digital image measurements," *Adv. Eng. Inf.* **33**, 96–111 (2017).
249. D. L. Marini, C. Bonanomi, and A. Rizzi, "Perceptual contrast enhancement in visual rendering of astrophotographs," *J. Electron. Imaging* **26**(3), 031205 (2017).
250. M. Lecca, A. Rizzi, and R. P. Serapioni, "GRASS: a gradient-based random sampling scheme for Milano Retinex," *IEEE Trans. Image Process.* **26**(6), 2767–2780 (2017).
251. P. Sahu, N. Gupta, and N. Sharma, "A survey on underwater image enhancement techniques," *Int. J. Comput. Appl.* **87**(13), 19–23 (2014).
252. Y. Wang, Q. Huang, and J. Hu, "Adaptive enhancement for nonuniform illumination images via nonlinear mapping," *J. Electron. Imaging* **26**(5), 053012 (2017).
253. V. W. de Dravo et al., "An adaptive combination of dark and bright channel priors for single image dehazing," *J. Imaging Sci. Technol.* **61**(4), 404081 (2017).
254. J. Yeonan-Kim and M. Bertalmío, "Analysis of retinal and cortical components of Retinex algorithms," *J. Electron. Imaging* **26**(3), 031208 (2017).
255. O. P. Verma and N. Sharma, "Efficient color cast correction based on fuzzy logic," *J. Eng. Sci. Technol. Rev.* **10**(3), 115–122 (2017).
256. M. Lecca, A. Rizzi, and R. P. Serapioni, "Great: a gradient-based color-sampling scheme for Retinex," *J. Opt. Soc. Am. A* **34**(4), 513–522 (2017).
257. A. Rizzi and C. Bonanomi, "Milano Retinex family," *J. Electron. Imaging* **26**(3), 031207 (2017).
258. G. Simone et al., "On edge-aware path-based color spatial sampling for Retinex: from Termite Retinex to light energy-driven termite Retinex," *J. Electron. Imaging* **26**(3), 031203 (2017).
259. J. Chauvin and E. Provenzi, "SLMRACE: a noise-free race implementation with reduced computational time," *J. Electron. Imaging* **26**(3), 031202 (2017).
260. H. Lu et al., "Underwater optical image processing: a comprehensive review," *Mob. Networks Appl.* **22**(6), 1204–1211 (2017).
261. F. Pierre et al., "Variational contrast enhancement of gray-scale and RGB images," *J. Math. Imaging Vision* **57**(1), 99–116 (2017).
262. G. Gianini and A. Rizzi, "A fuzzy set approach to Retinex spray sampling," *Multimedia Tools Appl.* **76**(23), 24723–24748 (2017).
263. M. Lecca, "Using color and local binary patterns for texture retrieval," *Cultura e* (2017).
264. A. S. A. Ghani and N. A. M. Isa, "Automatic system for improving underwater image contrast and color through recursive adaptive histogram modification," *Comput. Electron. Agric.* **141**, 181–195 (2017).
265. Q.-C. Tian and L. D. Cohen, "Color consistency for photo collections without gamut problems," *Lect. Notes Comput. Sci.* **10132**, 90–101 (2017).
266. E. Provenzi, "Similarities and differences in the mathematical formalizations of the Retinex model and its variants," *Lect. Notes Comput. Sci.* **10213**, 55–67 (2017).
267. X. Deng et al., "State of the art of the underwater image processing methods," in *IEEE Int. Conf. Signal Process., Commun. and Comput.*, pp. 1–6, IEEE (2017).
268. S. W. Zamir et al., "Perceptually-inspired gamut mapping for display and projection technologies," PhD Thesis, Universitat Pompeu Fabra (2017).
269. Y. Wang, "Learning based image analysis with application in dietary assessment and evaluation," PhD Thesis, Purdue University (2017).
270. H. Lu, Y. Li, and S. Serikawa, "Computer vision for ocean observing," in *Artificial Intelligence and Computer Vision*, H. Lu and Y. Li, Ed., pp. 1–16, Springer, Cham (2017).
271. O.-M. Machidon and M. Ivanovici, "Digital color restoration for the preservation of reversal film heritage," *J. Cult. Heritage* **33**, 181–190 (2018).

272. M. Lecca, "STAR: a segmentation-based approximation of point-based sampling Milano Retinex for color image enhancement," *IEEE Trans. Image Process.* **27**(12), 5802–5812 (2018).
273. X. Fu et al., "Pedestrian detection by feature selected self-similarity features," *IEEE Access* **6**, 14223–14237 (2018).
274. M. Mangeruga, M. Cozza, and F. Bruno, "Evaluation of underwater image enhancement algorithms under different environmental conditions," *J. Marine Sci. Eng.* **6**(1), 10 (2018).
275. E. Provenzi, "Formalizations of the retinex model and its variants with variational principles and partial differential equations," *J. Electron. Imaging* **27**(1), 011003 (2017).
276. X. Huang et al., "Smartphone-based analytical biosensors," *Analyst* **143**(22), 5339–5351 (2018).
277. D. L. Marini, C. Bonanomi, and A. Rizzi, "About color correction in astrophotography," *Electron. Imaging* **2018**(16), 285-1–285-5 (2018).
278. M. Han et al., "A review on intelligence dehazing and color restoration for underwater images," *IEEE Trans. Syst. Man Cybern.* **50**, 1820–1832 (2020).
279. N. N. Xiong et al., "Color sensors and their applications based on real-time color image segmentation for cyber physical systems," *EURASIP J. Image Video Process.* **2018**(1), 1–16 (2018).
280. R. Xie et al., "Guided color consistency optimization for image mosaicking," *ISPRS J. Photogramm. Remote Sens.* **135**, 43–59 (2018).
281. V. Vonikakis, R. Kouskouridas, and A. Gasteratos, "On the evaluation of illumination compensation algorithms," *Multimedia Tools Appl.* **77**(8), 9211–9231 (2018).
282. N. Banić and S. Lončarić, "Green stability assumption: unsupervised learning for statistics-based illumination estimation," *J. Imaging* **4**(11), 127 (2018).
283. E. Roe and C. A. Mello, "Thresholding color images of historical documents with preservation of the visual quality of graphical elements," *Integrated Comput.-Aided Eng.* **25**(3), 261–272 (2018).
284. D. Garg, N. K. Garg, and M. Kumar, "Underwater image enhancement using blending of CLAHE and percentile methodologies," *Multimedia Tools Appl.* **77**(20), 26545–26561 (2018).
285. H. Fu et al., "Perception oriented haze image definition restoration by basing on physical optics model," *IEEE Photonics J.* **10**(3), 1–16 (2018).
286. G. Bae et al., "Non-iterative tone mapping with high efficiency and robustness," *IEEE Access* **6**, 35720–35733 (2018).
287. J.-L. Lisani, "An analysis and implementation of the shape preserving local histogram modification algorithm," *Image Process. On Line* **8**, 408–434 (2018).
288. H. Tateyama and S. Kuriyama, "Perceptual color enhancement for led illuminations," in *5th Int. Conf. Adv. Inf.: Concept Theory and Appl.*, IEEE, pp. 118–123 (2018).
289. J. L. Lisani, "Adaptive local image enhancement based on logarithmic mappings," in *25th IEEE Int. Conf. Image Process.*, pp. 1747–1751 (2018).
290. R. Sethi and S. Indu, "Local enhancement of SLIC segmented underwater images using gray world based algorithm," in *Ninth Int. Conf. Adv. Pattern Recognit.*, IEEE, pp. 1–6 (2017).
291. J. S. Romero et al., "Implementation and optimization of the algorithm of automatic color enhancement in digital images," in *IEEE Int. Autumn Meeting Power, Electron. and Comput.*, IEEE, pp. 1–6 (2017).
292. J. Su and L. Liu, "New automatic color equalization algorithm based on lateral inhibition mechanism," in *IEEE 4th Inf. Technol. and Mechatron. Eng. Conf.*, IEEE, pp. 1592–1595 (2018).
293. J. Zhao, J. Li, and Y. Ma, "RPN+ fast boosted tree: combining deep neural network with traditional classifier for pedestrian detection," in *4th Int. Conf. Comput. and Technol. Appl.*, pp. 141–150 (2018).
294. Y. H. Roohani and E. G. Kiss, "Improving accuracy of nuclei segmentation by reducing histological image variability," *Lect. Notes Comput. Sci.* **11039**, 3–10 (2018).
295. J. Osterloff, "Computer vision for marine environmental monitoring," PhD Thesis, University of Bielefeld (2018).

296. Q.-C. Tian, “Color correction and contrast enhancement for natural images and videos,” PhD Thesis, Université Paris Dauphine (2018).
297. M. Yang et al., “An in-depth survey of underwater image enhancement and restoration,” *IEEE Access* **7**, 123638–123657 (2019).
298. A. Gallo et al., “Performance evaluation of underwater image pre-processing algorithms for the improvement of multi-view 3d reconstruction,” *ACTA IMEKO* **8**(3), 69–77 (2019).
299. C. Tang et al., “Efficient underwater image and video enhancement based on Retinex,” *Signal Image Video Process.* **13**(5), 1011–1018 (2019).
300. J.-L. Lisani et al., “Analyzing center/surround Retinex,” *Inf. Sci.* **512**, 741–759 (2020).
301. A. Plutino et al., “Work memories in super 8: searching a frame quality metric for movie restoration assessment,” *J. Cult. Heritage* **41**, 238–248 (2020).
302. W. Wang, N. Sun, and M. K. Ng, “A variational gamma correction model for image contrast enhancement,” *Inverse Probl. Imaging* **13**(3), 461 (2019).
303. R. Sethi and I. Sreedevi, “Adaptive enhancement of underwater images using multi-objective PSO,” *Multimedia Tools Appl.* **78**(22), 31823–31845 (2019).
304. X. Deng, H. Wang, and X. Liu, “Underwater image enhancement based on removing light source color and dehazing,” *IEEE Access* **7**, 114297–114309 (2019).
305. M. Lecca and S. Messelodi, “SuPeR: Milano Retinex implementation exploiting a regular image grid,” *J. Opt. Soc. Am. A* **36**(8), 1423–1432 (2019).
306. E. Prado et al., “3D modeling of Rio Miera wreck ship merging optical and multibeam high resolution points cloud,” *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **XLII-2/W10**, 159–165 (2019).
307. N. Chong, L.-K. Wong, and J. See, “GANmera: reproducing aesthetically pleasing photographs using deep adversarial networks,” in *Proc. IEEE Conf. Comput. Vision and Pattern Recognit. Workshops* (2019).
308. S. A. Iliukhin et al., “A method for spatially weighted image brightness normalization for face verification,” *Proc. SPIE* **11041**, 1104118 (2019).
309. E. Birukov, M. Kopylov, and A. Khlopina, “Correction of Color Saturation for Tone Mapping Operator,” *Graphicon*, pp. 58–61 (2019).
310. A. Plutino, M. Lecca, and A. Rizzi, “A cockpit of measures for image quality assessment in digital film restoration,” *Lect. Notes Comput. Sci.* **11808**, 159–169 (2019).
311. A. Rizzi et al., “Spatial models of color for digital color restoration,” in *Conservation, Restoration, and Analysis of Architectural and Archaeological Heritage*, C. Inglese and A. Ippolito, Eds., pp. 386–404, IGI Global (2019).
312. M. Chambah et al., “Underwater color constancy: enhancement of automatic live fish recognition,” *Proc. SPIE* **5293**, 157–168 (2003).

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