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Image Color Enhancement Methods: An Experiment-Based Review

Zainab Khalid Younis [1*], Mohd Shafry Mohd Rahim [2], Farhan Bin Mohamed [3]

[1] *Department of Computer Science, College of Computer Science and Mathematics, University of Mosul, Mosul, Nineveh, Iraq*

[1,2,3] *Department of Computer Science, Faculty of Computing, Universiti Teknologi Malaysia (UTM), Skudai, 81310, Johor Bahru, Malaysia*

[*] zainab.younis@uomosul.edu.iq

Abstract

Color image enhancement is a vital area in the field of image processing. It is a technique used to enhance the image's visual quality. Color enhancement is applied in different applications such as photography, medicine, and computer vision. In this research, eight methods of color enhancement are reviewed according to their methodology, complexity, pros, and cons. Then, three evaluation metrics used Colorfulness (CF), average saturation measure (ASM), and average chroma measure (ACM) to assess each method. The result showed that fuzzy enhancement (FE) exceeded other methods and scored the highest records. This study provides a beneficial resource for researchers involved in image enhancement, as it presents a complete review and detailed analysis of various academic studies published in reputable journals. The work evaluates each study in terms of its findings, proposed algorithm, and accuracy by using many assessment metrics. Furthermore, it emphasizes the strengths and limitations of each method, giving a performance analysis. Additionally, the study discusses future recommendations for improving the effectiveness of these algorithms. Finally, this research is a rich and reliable reference for scholars aiming to develop novel algorithms in this domain.

Keywords: Color enhancement, color model, image enhancement, image processing.

I. INTRODUCTION

IMAGE processing is the application of complex mathematical computation and special techniques on images to enhance, analyze, and manipulate these images for use in different applications [1]. The foremost crucial aspect of image processing is image enhancement, which increases the image's quality and visibility using a process of filtering to improve visual appearance or to use it in further analyses [4]. Image processing filters are used in different real-life applications, but the most common is digital photography [5]. The most used filters are denoising, deblurring, contrast enhancement, illumination adjustment, image sharpening, and color enhancement [35]. Figure 1 illustrates real-life examples of image degradations and the counterpart image processing filters. In recent years, color enhancement has gained significant attention from vendors and users as images with vibrant colors are in high demand globally. Color enhancement is used in artistic images to restore true color representation, reduce distortion, and improve overall visual impact [36]. Color enhancement is atoning color attributes to enhance image fidelity like hue, saturation, and so on to reach a better image quality and alluring visual aesthetic [6] or from color distortion for underwater images for physical reasons [7].

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Color enhancement techniques are demanded in various devices, such as mobile devices, video streaming, or computer vision applications, where it is crucial to retain excellent visual quality while using effective computational resources [37]. Statistics reveal that more than 80% of human data and knowledge is described as visual; the most crucial criterion is color because it inspires sensation, helps confinement memory, and facilitates image analysis [6]. A digital image is an item, setting, or topic represented visually, kept, and presented digitally [2]. This image comprises a grid of pixels that cipher a specific color value; combining all these digits performs the whole visual picture [3]. Digit depth regulates color range and color spaces categorized gamut [9]. Colors play a major role in digital images through eternal fundamental visual information, giving the images meaning and aesthetic demand. [10]. According to many circumstances, the digital image suffers many degradations, leading to low visual quality and legibility for color distinctness and clarity [8] [11].

Fig. 1. Real-life examples of image degradations and the counterpart image processing filters. Row (1): images from left to right are degraded by uneven illumination, blurring, noise, low-contrast, and deficient colors. Row (2): Images of row (1) processed by image processing filters of Illumination adjustment, deblurring, denoising, contrast enhancement, and color enhancement.

The most common reasons behind these unpleasant color images are inadequate light, substandard exposure, imperfect sensors, extreme compression, and environmental issues such as the atmosphere [12]. Therefore, many algorithms and methods have been conducted to improve color images in both spatial and frequency domains [13]. Color is the most used image feature independent of image resolution or orientation. A color model is a mathematical scheme for representing colors as numerical values, accustomed to ensuring dependable color reproduction in digital images and graphics [14]. There is no single best color representation; the target application plays an important role in determining which color model is best; the most frequently utilized color models are RGB, HS* family (HSL, HSV), CIELAB, CMYK, Munsell, and fuzzy color models.

HSL color space divides color information into hue ('H'), saturation ('S'), and lightness ('L'). In RGB color space, color information is resolute solely by the ratio between three interdependent channels. In the HSL color space, the lightness component "L" is distinct from and unrelated to the saturation component "S," which refers to how color is perceived in an image, and the chrominance component "H," which refers to a picture's color details. Lightness determines the image information when saturation and chrominance stay constant [39]. HSV color space consists of hue (H), saturation (S), and value (V), which are the three channels. The final one is a brightness signifier, while the first two are color signifiers. The H, S, and V channels decouple because they are equilateral [40]. In CIELAB color space, the difference between two color coordinates is directly proportional to how differently humans perceive the corresponding two colors. Because of their consistency, the CIELAB color spaces are superior to the RGB in color representation [41].

These models vary depending on key features like human consistency, uniformity, correlation, complexity, conversion time to RGB (source image format), effectiveness, precise color specification, and image indexing [15]. Color and color enhancement are becoming more fundamental due to expeditious technological improvements, like 4K and HDR displays, increasing consumer assumptions for vivid and accurate visuals. Adequate image color enhancement ensures that digital content and products meet these high standards, impacting customer satisfaction by delivering a visually appealing and engaging experience [16] [17]. The rest of the article is organized as follows: Section 2 explains various concepts of color enhancement methods in-depth and the results on different degraded images; Section 3 demonstrates the quality evaluation metrics, the dataset, the obtained results, and the associated analysis. Section 4 gives essential conclusions for this review.

II. COLOR ENHANCEMENT METHODS

Different researchers have utilized various concepts for color image enhancement, including Histogram Equalization [18], Single scale Retinex and multiscale Retinex [19] [25], Contrast stretching [20], Homomorphic Filter [21][26], Deep learning [22], and fuzzy [23] [27]. As for this color image enhancement, eight methods will be reviewed in the upcoming sub-sections, and Table 1 demonstrates a synopsis of the studied color enhancement methods.

TABLE 1:
SYNOPSIS OF THE STUDIED COLOR ENHANCEMENT METHODS

No.	Researcher / Year	Technique	Complexity	Advantages/ Disadvantages	Future Directions
1.	Mukherjee & Mitra, 2008	Scaling with Tau (SWT)	Above moderate	Increase the colors/ brightness amplification and blocking artifacts	Eliminate the blocking effect and preserve the brightness.
2.	Shen & Hwang, 2009	Retinex with Envelope (RWE)	High	Adequate contrast/ blocking artifact and	Eliminate the blocking artifact/ improve colors
3.	Zhang, Y., & Xie, M. 2013	Global Homomorphic Filtering (GHF)	moderate	Can improve the colors / dramatical brightness increase	Preserve the brightness while boosting the colors
4.	Mandal et al., 2020	Fuzzy Enhancement (FE)	Low	Proper enhancement ability / overall appearance tends to be reddish	Handle the color shift effect properly
5.	Katırcıoğlu, 2020	Heat Conduction Array (HCA)	High	Sharp details/ low-color enhancement	Better improve the colors.
6.	S. Sun et al., 2021	adaptive method combination (AMC)	Low	Can modify the color / the output colors are pale	Better improve the colors
7.	Azetsu et al., 2022	limited hues (LH)	Below moderate	can improve the color/contrast slightly limited	better improve the contrast
8.	Al-Ameen, 2023	Tint Intensification (TI)	Low	Proper color enhancement / not fully automatic	Improve the method to fully automatic

The eight reviewed methods, such as Scaling with Tau (SWT), Retinex with Envelope (RWE), and Global Homomorphic Filtering (GHF), determine important innovations for enhancing color and brightness in images. Nevertheless, each method has weaknesses, such as blocking artifacts, color shifting, and insufficient automatic processing. These deficiencies recommend a need for further refinement in the existing approaches. Increasing motivation for the review by stating why current methods are inadequate, for example, how they decline to fully tackle issues like color consistency, automation, or contrast enhancement, would give a more precise context. By addressing how the review addresses these gaps, the paper can introduce a more thorough and significant examination of the condition of color enhancement techniques, offering valuable insights for future research and development.

III. RESEARCH METHOD

A. Scaling with Tau (SWT)

Mukherjee & Mitra (2008) [24] introduced the SWT algorithm, where the input image is first in the YUV domain and the required parameters. Then, some statistics. The calculation is specified along with the threshold. Next, the image is divided into several sub-blocks; calculate the gain factor for each sub-block. Back Each sub-block is scaled by a gain factor, and the sub-blocks are then combined into an output image. The result of this method can be seen in Fig. 2.

Fig. 2. The SWT method. Row (1) Poor color images; Row (2) The enhancement results of the SWT method.

B. Retinex with Envelope (RWE)

Shen & Hwang (2009) [25] proposed the RWE algorithm. It receives the input image, converts it to the HSV domain, and only processes the V channel while keeping the other two channels unchanged. Enhancement on the V channel is achieved by applying an estimator to determine the illuminated part of the image. The estimated information is then processed using illumination correction methods. Next, the envelope method is applied, which uses a gradient-dependent weighting method to prevent halo artifacts from forming and generating an output image. In 2012, spec-based histograms were created. The result of this method can be seen in Fig. 3.

Fig. 3. The RWE method. Row (1) Poor color images; Row (2) The enhancement results of the RWE method.

C. Global Homomorphic Filtering (GHF)

Zhang, Y., & Xie, M. (2013) [26] introduced global homomorphic filtering (GHF) and local homomorphic filtering (LHF) were introduced by starting by converting the input to HSI color space. Then, the hue and saturation channels are left unchanged while the intensity channel is modified using a global homomorphic filter for GHF and a local homomorphic filter for LHF. Finally, the processed image is returned to the RGB domain to obtain the output image. The result of this method can be seen in Fig. 4.

Fig. 4. The GHF method. Row (1) Poor color images; Row (2) The enhancement results of the GHF method.

D. Fuzzy Enhancement (FE)

Mandal et al. (2020) [27] proposed a blur-based enhancement algorithm (FE), which first converts the received image into LAB color space. Next is the blurred histogram of channel L certainly. Then, the threshold process is used to determine overexposed and underexposed parts. Then, balance them, calculate, and convert two specific components to return the image to RGB color space to produce an output image. The result of this method can be seen in Fig. 5.

Fig. 5. The FE method. Row (1) Poor color images; Row (2) The enhancement results of the FE method.

E. Heat Conduction Array (HCA)

Katırcıoğlu (2020) [28] introduced the HCA, a model that starts with color stretching of the entire image. Next, the filtered image is converted to the HSI domain, and for each pixel in the channel I, the HCM is calculated and applied and then outputs the threshold set in the previous step. The last one is to realize the conversion from the HSI domain to the RGB domain, and the output image is produced. The result of this method can be seen in Fig. 6.

Fig. 6. The HCA method. Row (1) Poor color images; Row (2) The enhancement results of the HCA method.

F. Adaptive Method Combination (AMC)

Sun et al. (2021) [29] proposed the AMC for color enhancement by calculating a strict ordering process determined strength. Next, addition and multiplication were applied to improve color and color enhancement methods. The results are then adaptively combined to create the resulting image. The result of this method can be seen in Fig. 7.

Fig. 7. The AMC method. Row (1) Poor color images; Row (2) The enhancement results of the AMC method.

G. Limited Hues (LH)

Azetsu et al. (2022) [30] created the LH, an algorithm that first converts the received image into the CIELAB color space. Next, a size-based enhancement method is applied to increase image saturation. Special intensity transformation methods are then used to adjust the color space. Finally, convert to the RGB domain to create the output image. The result of this method can be seen in Fig. 8.

Fig, 8. The LH method. Row (1) Poor color images; Row (2) The enhancement results of the LH method.

Fig. 9. The TI method. Row (1) Poor color images; Row (2) The enhancement results of the TI method.

H. Tint Intensification (TI)

Al-Ameen's (2023) [31] research introduced the TI algorithm that can enhance colors by first converting the image to the HSV domain and preserving the hue channel while processing the other two saturation and value channels with a different concept. The image is then converted to the RGB domain. Using a variety of methods for reprocessing produces the desired output. The result of this method can be seen in Fig. 9.

Pseudo-code for TI method:

Input: poor-color image, tuning parameter
RGB to HSV conversion.
S channel filtering with **GLAT**.
V channel filtering with **sine** and **arctangent of sin**.
HSV to RGB conversion.
Applying **RCDF** filtering.
Apply the **min-max scaling**.
Output: Color-enhanced image

IV. RESULTS AND DISCUSSION

This part of the study demonstrates several aspects, including the dataset used, the quality evaluation metrics, the results attained, and the related analysis. It also describes the computer specifications and compares and analyzes all methods used objectively and subjectively, giving a clear overview of the findings. The dataset of this study is collected from four different resources. The first source is a collection of digitized normal images from various appropriate databases. The first dataset is taken from https://data.csail.mit.edu/graphics/fivek/. The MIT-Adobe FiveK Dataset [38] is an online repository that contains 5,000 photos taken by different photographers using DSLR cameras. All these images are in RAW format, meaning all information recorded by the camera sensor is retained.

The second dataset type is a self-collected dataset from dissimilar mobile devices such as iPhone 7 plus, iPhone 13 ProMax, Samsung Galaxy A36, and Galaxy Note 20 Ultra. The images for all types are colored photos with different sizes, for example, a minimum of 2000*2000 pixels. Images collected from MIT-Adobe FiveK Dataset, a DNG format, are abbreviated as Digital Negative Format and are universal RAW image formats developed by Adobe. RAW files, also known as digital negatives, are a lossless format that captures uncompressed data from a camera. There are three evaluation metrics applied in this research: colorfulness factor (CF) [32], average saturation measure (ASM) [33], and average chroma measure (ACM) [34] to measure and assess the reviewed methods.

TABLE 2
THE RT↓ SCORES

#	Methods	Galaxy A36	Galaxy Note 20 Ultra	iPhone7 Plus	iPhone13 Pro Max	MIT	Average
1	SWT	97.660579	59.851394	92.518470	94.073426	55.630930	79.947
2	RWE	367.478327	332.168284	355.027564	366.099082	284.343976	341.023
3	GHF	58.135373	60.512875	53.181091	53.941698	34.042382	51.9627
4	FE	9.724545	6.823196	9.417556	9.685456	6.809548	8.49206
5	HCA	521.410192	264.179304	374.091341	275.136939	192.007915	325.365
6	AMC	1.795244	1.117128	1.141433	1.527552	1.063886	1.32905
7	LH	9.366878	7.133094	9.765113	9.486200	6.483516	8.44696
8	IT	3.120615	1.969071	2.999513	3.007839	2.096706	2.63875

First, using some calculations, the reduced reference (RR) method named CF is used to assess color complexity and improvement between a color-tainted image and the original image. This evaluation method results in a numerical value with three different directions: if the CF is less than 1, the original (pristine) image has good color. If the CF is greater than 1, the enhanced image has more color than the original image. Lastly, the CF = 1 means the original and tainted image has the same color. Therefore, a higher value indicates better color. Second, ASM is a no-reference metric that assesses the color saturation in the image and reflects the intensity by how the image is pale or intense for evaluation of color. It brings a predictable level of vitality to the whole image. The value for ASM should be more than 0. The higher value indicates the image colors are more vibrant and vice versa.

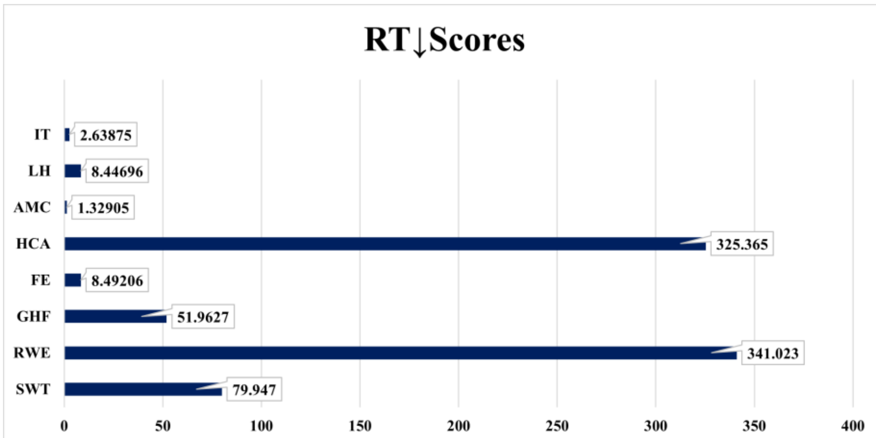

Fig. 9. Average RT readings.

TABLE 3
THE CF ↑ SCORES

#	Methods	Galaxy A36	Galaxy Note 20 Ultra	iPhone7 Plus	iPhone13 Pro Max	MIT	Average
1	SWT	53.1245	42.0921	24.8112	25.3177	35.6243	36.19396
2	RWE	57.8576	51.2898	30.1387	29.8443	38.1392	41.45392
3	GHF	50.9958	45.2476	24.1731	26.9591	32.3539	35.9459
4	FE	50.6886	50.0303	27.8326	54.1721	34.5934	43.4634
5	HCA	38.2895	36.6894	16.7543	21.8829	22.5063	27.22448
6	AMC	33.3704	31.2116	15.9245	16.6859	22.4547	23.92942
7	LH	50.2564	46.0682	21.8229	28.3545	29.2507	35.15054
8	IT	62.4708	53.7746	31.8671	43.9449	41.2764	46.66676

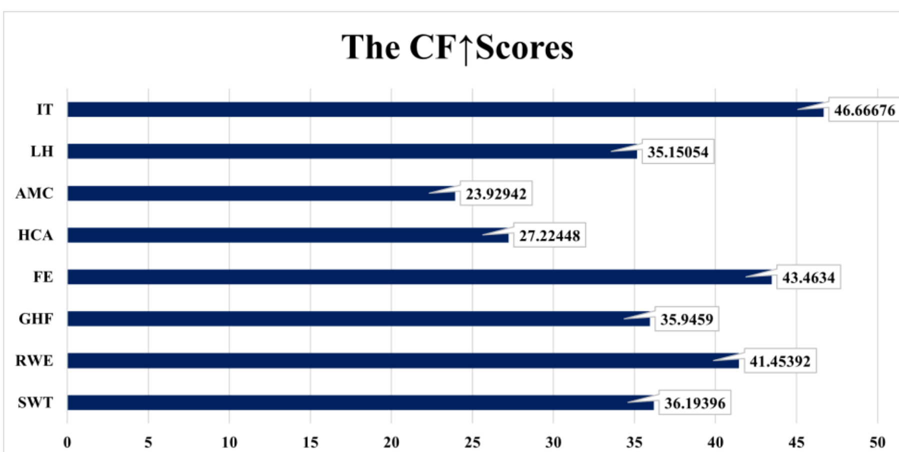

Fig. 10. Average CF readings.

ACM is a no-reference metric used to measure color intensity, where C is the Chroma that refers to the description of color, which contains intensity and saturation. If ACM values are more than 0, indicate the image has more informative and intense colors and vice versa. Runtimes are also computed to determine the complexity of each method. Regarding hardware specifications and programming environment, all experiments have been conducted using a MATLAB R2018a environment on a machine with a Core i7-8650U, 1.90GHz CPU, and 16 GB of RAM. The eight reviewed methods are categorized into the following ranks: worst, very low, low, average, above average, high, above high, best. All reviewed methods are identified in Figure 1 to Figure 8. In addition, all the numerical results of the evaluated methods are provided with their average and can be shown from Table 2 to Table 5.

TABLE 4
The ASM↑ scores,

#	Methods	Galaxy A36	Galaxy Note 20 Ultra	iPhone7 Plus	iPhone13 Pro Max	MIT	Average
1	SWT	0.30233	0.22342	0.1503	0.13872	0.22143	0.20724
2	RWE	0.31452	0.23416	0.15206	0.1506	0.22308	0.214884
3	GHF	0.31341	0.23308	0.15215	0.15007	0.22361	0.214464
4	FE	0.43165	0.38062	0.30045	0.39215	0.36561	0.374096
5	HCA	0.31905	0.23426	0.15572	0.15245	0.22367	0.21703
6	AMC	0.20313	0.15721	0.093756	0.095178	0.16037	0.1419288
7	LH	0.40311	0.29714	0.19414	0.18925	0.2856	0.273848
8	IT	0.49842	0.38794	0.27716	0.28441	0.39742	0.36907

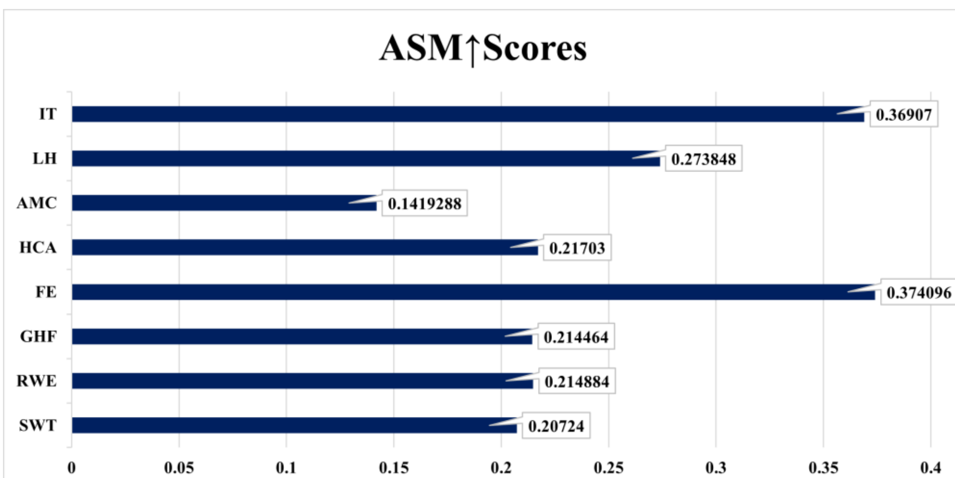

Fig. 11. Average ASM readings.

Fig. 9 to 12 present the bar chart of the average reading of all the metrics used and the runtime readings. From the previously given results, the SWT algorithm provides improper output by amplifying brightness and blocking artifacts for the image while increasing the colors. This is why it is recorded above average for CF ACM metrics respectively and very- low for ASM metrics, ranking it 4th among other competitors. The SWT scored above average for runtime. The RWE presents satisfactory contrast but a blocking artifact. This result led to high scores reading for CF and ACM metrics and an average for ASM metrics, which ranks 3rd among other methods. For runtime, it is the worst. The GHF improved images with brightness, increased dramatically, and needed increased colors, which made it score average for CF, ACM, and low for ASM and ranked 5th among other competitors. For runtime, scored average.

The FE yields appropriate color enhancement, but the low brightness and image appear reddish; therefore, its ASM and ACM scores are best and high for CF, which makes it ranked the best among other competitors' methods, with first ranking for both metrics scores and runtime. The HCA processed good detail sharpening with low color. This result makes it score very low according to CF and ACM, above average for ASM, leading to ranking 7th among other methods and runtimes, respectively. On the other hand, the AMC method produces a modified color that presents a pale color that needs to improve; therefore, it scored the worst according to the evaluation metrics CF, ASM, ACM, and very high runtime, ranking 8th among the rest of the participants. The LH algorithm improved color with imperfect contrast, which made it limited; for this reason, it scored low readings for CF and ACM metrics and scored high for ASM metric readings, making it ranked 6th according to other methods; runtime scored low. TI has produced proper color enhancement and contrast, but it is not automatic. With this result, this TI scored best for CF and very high for ASM and ACM. Thus, it ranked 2nd among other methods, with very low runtime score. Finally, all these methods were analyzed according to the achievement of each reviewed method according to implantation time and accuracy in terms of color enhancement, contrast, and other artifacts.

TABLE 5
THE ACM↑ SCORES

#	Methods	Galaxy A36	Galaxy Note 20 Ultra	iPhone7 Plus	iPhone13 Pro Max	MIT	Average
1	SWT	22.1024	15.2146	9.1069	8.1133	15.9748	14.1024
2	RWE	24.2403	18.1449	10.7453	9.6224	17.3334	16.01726
3	GHF	21.5329	15.7585	8.9703	8.4818	14.9990	13.9485
4	FE	23.3985	18.5799	13.5727	21.3855	18.2408	19.03548
5	HCA	16.5660	11.4032	6.4784	6.6586	10.9680	10.41484
6	AMC	13.7814	10.4707	5.5201	5.2645	10.5359	9.11452
7	LH	21.4678	14.6872	8.4993	8.7413	14.3002	13.53916
8	IT	26.4182	18.0457	12.5171	13.9534	19.4791	18.0827

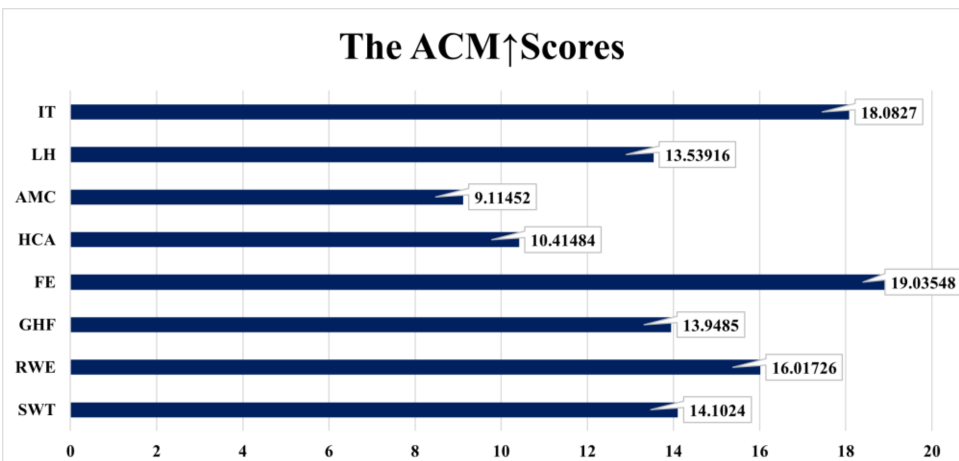

Fig. 12. Average ACM readings.

V. CONCLUSION

To conclude, this research reviewed eight color image enhancement methods. Each method was comprehensively discussed, and its basic mechanism was thoroughly explained. The data images were varied and tested by each method, and all results were generated and presented properly. All illustration tables and figures for color enhancement methods were provided, such as a synopsis table containing all authors' details, year, pros, cons, future directions, and the technique used for each method. The data was collected from multiple sources. The first source was a website specializing in natural images. The second resource was a photograph collected from various mobile devices like the iPhone 7, iPhone 13, Galaxy A36, and Galaxy Ultra 20. The execution time was computed, recorded, and presented in a table called (RT) for each reviewed method with each tested image and its average. Then, three proceeding methods were employed to assess the accuracy of the images for each approach, with the results summarized in tables and charts, including the specified measurements. Finally, all results were analyzed by evaluating the performance of each method, considering several aspects, for instance, implementation time and accuracy, in terms of complexity, intensity, contrast, brightness, and naturalness.

DATA AND COMPUTER PROGRAM AVAILABILITY

The data and source codes used in this paper can be accessed on the following sites: mathworks.com and github.com.

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