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Article

Eight-Scale Image Contrast Enhancement Based on Adaptive Inverse Hyperbolic Tangent Algorithm

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Abstract: The Eight-Scale parameter adjustment is a natural extension of Adaptive Inverse Hyperbolic Tangent (AIHT) algorithm. It has long been known that the Human Vision System (HVS) heavily depends on detail and edge in the understanding and perception of scenes. The main goal of this study is to produce a contrast enhancement technique to recover an image from blurring and darkness, and at the same time to improve visual quality. Eight-scale coefficient adjustments can provide a further local refinement in detail under the AIHT algorithm. The proposed Eight-Scale Adaptive Inverse Hyperbolic Tangent (8SAIHT) method uses the sub-band to calculate the local mean and local variance before the AIHT algorithm is applied. This study also shows that this approach is convenient and effective in the enhancement processes for various types of images. The 8SAIHT is also capable of adaptively enhancing the local contrast of the original image while simultaneously extruding more on object details.

Keywords: eight-scale; sub-band; adaptive inverse hyperbolic tangent; contrast enhancement

1. Introduction

In human visual perception, contrast has a significant influence on the quality of an image. Contrast enhancement is frequently referred to as one of the most important issues in image processing. A poorly-illuminated environment can significantly affect the contrast ratio, producing an unexpected image. Contrast is created by the difference in luminance reflected from two adjacent surfaces. Several studies have given particular attention to this subject.

Local contrast stretching is an enhancement method performed on an image for locally adjusting each picture element value in order to improve the visualization of structures in both the darkest and lightest portions of an image at the same time. Local contrast stretching is performed by sliding windows across the image and adjusting the center elements [1].

Global contrast stretching is simple and fast, but its contrast-enhancement power is relatively low. Local contrast stretching, on the other hand, can more effectively enhance overall contrast, but the complexity of computation required is very high due to its fully overlapped sub-blocks [2]. The global contrast stretching method is simple and powerful, but it cannot adapt to the local brightness features of the input image because it uses only global information over the whole image. This fact limits the contrast-stretching ratio in some parts of the image, and causes significant contrast losses in the background and other small regions.

To overcome this limitation, this study proposes an Eight-Scale Adaptive Inverse Hyperbolic Tangent (8SAIHT) method. This technique consists of two steps: a sub-scale step and a contrast enhancement step. The sub-scale step is applied to the image for sub-band processing. In the contrast enhancement step, the Adaptive Inverse Hyperbolic Tangent (AIHT) algorithm is applied for contrast enhancement, and to bring out hidden details. The new value of remapped pixel is based on an AIHT map function. Test results indicate that the proposed method could provide better image contrast than conventional enhancement methods in terms of visual looks and image details.

2. Adaptive Inverse Hyperbolic Tangent Algorithm

This AIHT form fits data obtained from measuring the electrical response of photo-receptors to flashes of light in various space [3]. It has also provided a good fit to other electro-physiological and psychophysical human visual function measurements [4–6]. The inverse hyperbolic tangent of a value x is the value y for which the hyperbolic tangent of y is x. The inverse hyperbolic tangent function is only defined in the open range (−1, +1). This corresponds to the output range of the hyperbolic tangent function.

The calculation for $\tanh^{-1}(x)$ can be derived either algebraically from the definition of $\tanh^{-1}(x)$, or by converting the derivative to a series and then integrating. The contrast of an image can be enhanced using inverse hyperbolic tangent function by Equation (1):

$$y = \tanh^{-1}(x) = \frac{1}{2}\log\left(\frac{1+x}{1-x}\right) \tag{1}$$

Adding the *bias(x)* and *gain(x)* parameters to control the shape of the inverse hyperbolic tangent curve leads to Equation (2):

$$Enhance\left(x_{ij}\right)=\left(\log\left(\frac{1+x_{ij}^{bias(x)}}{1-x_{ij}^{bias(x)}}\right)-1\right)\times gain\left(x\right) \tag{2}$$

where *bias(x)* represents the Bias Power Function, and *gain(x)* represents the Gain Function described in the following paragraphs.

In the AIHT algorithm, the dark and bright regions are under- and over-saturated, respectively. There is insufficient enhancement in the dark and bright regions. In order to address this problem, and to avoid expending the large amount of time required in traditional contrast enhancement algorithms—which search optimal gray transform parameters in the whole gray transform parameters space—a new criterion is proposed with sub-band processing. This method introduces a new contrast enhancement algorithm designed specifically for segmentation applications using an image with different sub-bands. The underlying assumption of the proposed algorithm is that a sub-band can be best segmented if it is locally enhanced at a scale that corresponds to the image feature. The contrast type of the original image is determined by the new criterion. Gray transform parameter space is respectively determined by different contrast types, which dramatically shrinks the gray transform parameter space. Nonlinear transform parameters are based on a multi-scale *bias* and *gain* parameter algorithm so as to obtain optimal gray transform parameters [7–11]. This method is adaptive where the enhancement is applied locally, based on local image properties.

3. Eight-Scale Parameter Adjustment of Adaptive Inverse Hyperbolic Tangent Algorithm

The two-scale method is used to enlarge low and high luminance levels. It can be used to automatically adjust the local gain in low- and high-luminance images, making the local details visible. However, the two-scale method ignores medium luminance levels, and this is a potential problem. To address this, a transformation function must be provided that can also retain the linear characteristics for medium luminance levels. For most adaptive enhancements of any part of the luminance range, it can be expanded to four and eight scale models [12,13]. This transformation function has an adaptive enhancement rate for any part of the luminance range, and thus additionally so for details in the low, medium and high-luminance regions.

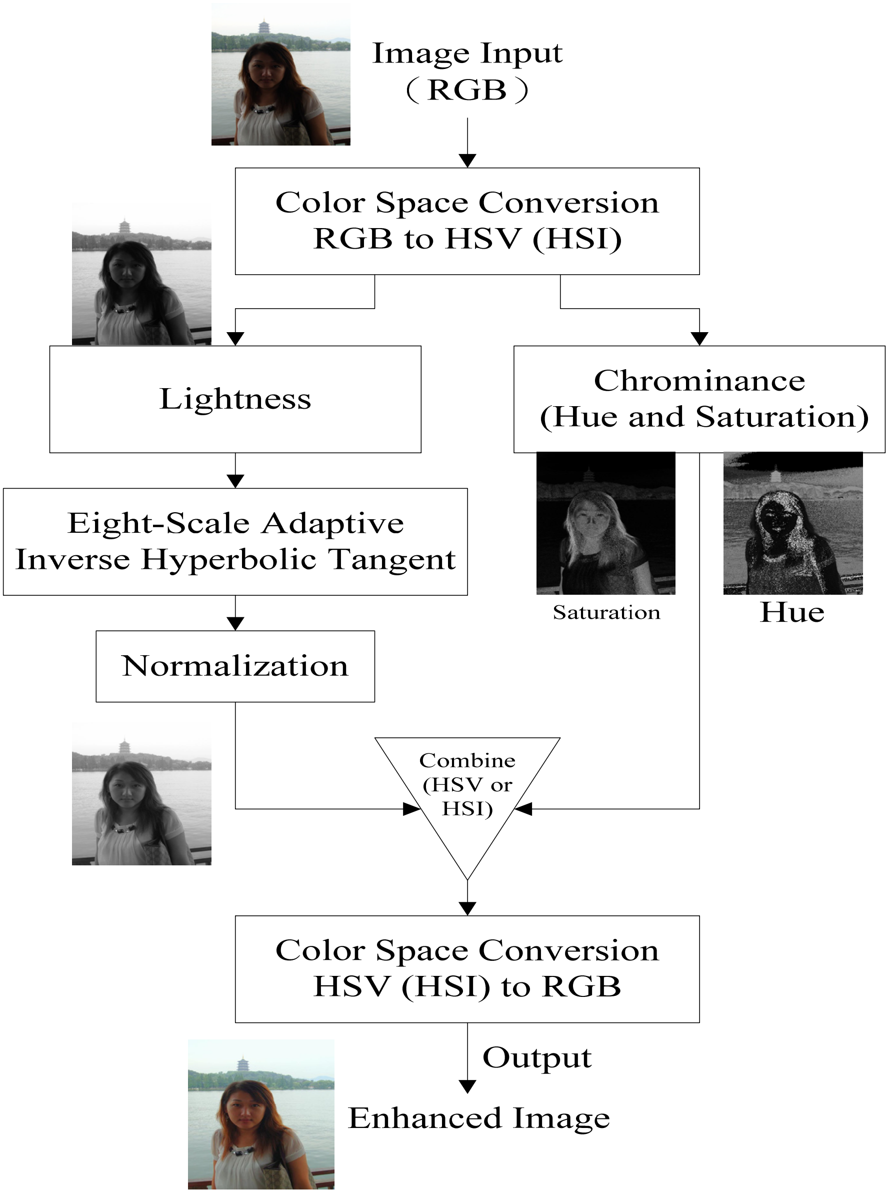
Figure 1 shows a block diagram of the 8SAIHT algorithm. The input data is converted from its original format to a floating point representation of RGB values. The principal characteristic of the proposed enhancement function is an eight-scale adaptive adjustment of the Inverse Hyperbolic Tangent algorithm, determined by each pixel's radiance.

Figure 2 shows a block diagram of 8SAIHT parameter values, including eight-scale *bias* and *gain* parameters. The 8SAIHT will use a range of inputs divided into eight bands for processing by its own parameters, respectively. After reading the image file, the eight-scale parameters (including $bias_{HHH}$, $gain_{HHH}$, $bias_{HHL}$, $gain_{HHL}$, $bias_{HLH}$, $gain_{HLH}$, $bias_{HLL}$, $gain_{HLL}$, $bias_{LHH}$, $gain_{LHH}$, $bias_{LHL}$, $gain_{LHL}$, $bias_{LLH}$, $gain_{LLH}$, $bias_{LLL}$ and $gain_{LLL}$) are computed. These parameters control the shape of the sub-band, respectively.

The enhanced output image Enhance_8SAIHT resulting from the eight-scale approach for processing input image x, is described by:

$$Enhance\_8SAIHT = \sum_{k=1}^{8} AIHT_{bias(k),\, gain(k)}(x_k) \tag{3}$$

Figure 1. A flowchart of the Eight-Scale Adaptive Inverse Hyperbolic Tangent (8SAIHT) algorithm.

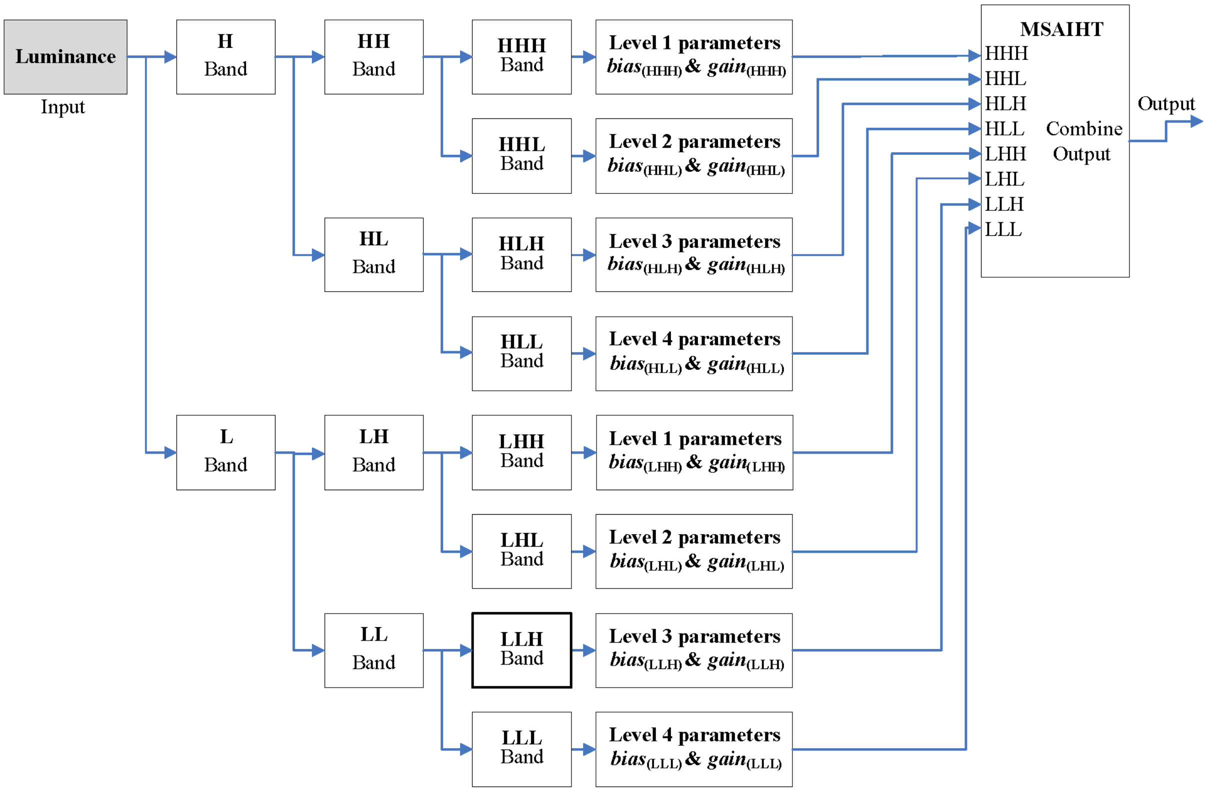


$$Enhance\_8SAIHT(x_{ij}) = \sum_{k=1}^{8} \left(\log \left(\frac{1 + x_{ij}^{\,bias(x_k)}}{1 - x_{ij}^{\,bias(x_k)}} \right) - 1 \right) \times gain(x_k) \tag{4}$$

where k is the number of sub-band used, and x_k is the sub-band image of the input image.

Eight-scale is used for the enhancement of the sub-band luminance levels. It will automatically adjust the local *gain* and *bias* in the sub-band luminance images, making details visible. This transformation function has high compression for the upper part of the luminance range, and will additionally compress details in the sub-band luminance regions.

Figure 2. A block diagram of 8SAIHT parameter values.



4. Implementation and Experiment Results

This study demonstrates the effectiveness of these methods (2SAIHT; 4SAIHT and 8SAIHT) by experiment; and by illustrating how the algorithm works and quantitatively measuring the improvement in the quality of segmentation. The performance of the proposed algorithm is also compared with those of the methods mentioned above. For a fair comparison all methods were modified so that they only performed row-wise enhancement. All methods were run on an Intel Core 2 Quad 2.83 GHz CPU with 2GB RAM and compiled on a Windows XP operating system with Math Works MATLAB version R2010a software.

Four types of extreme images are used: dark images, bright images, back-lit images and low-contrast images. The images are categorized into outdoor, indoor and aerial images. The images include Dawn, Morning, Afternoon and Night images. Images with different types of histogram distributions were tested. These include some daily life images that may arise in contrast to the poor image, and demonstrate the enhanced results. Figure 3 shows various types of images with bad contrast enhancement, and the results of the enhanced image processing by histogram equalization, Contrast Limited Adaptive Histogram Equalization, AIHT and the proposed Multi-Scale AIHT (MSAIHT) method. Figure 4 shows a comparison of local detail obtained using AIHT and MSAIHT (4SAIHT). The local detail of the enhanced MSAIHT is better than that of AIHT.

The comparative analysis between the proposed MSAIHT methods and popular existing methods shows the effectiveness of these methods. The MSAIHT technique is able to retain the sharpness of defect edges and local detail very well. Therefore, AIHT and MSAIHT are able to significantly enhance poor images, and will be helpful for defect recognition.

Figure 3. Various types of bad contrast images illustrating the difference between contrast enhancement by Contrast Limited Adaptive Histogram Equalization, Adaptive Inverse Hyperbolic Tangent (AIHT) and MSAIHT (including 2SAIHT, 4SAIHT and 8SAIHT).

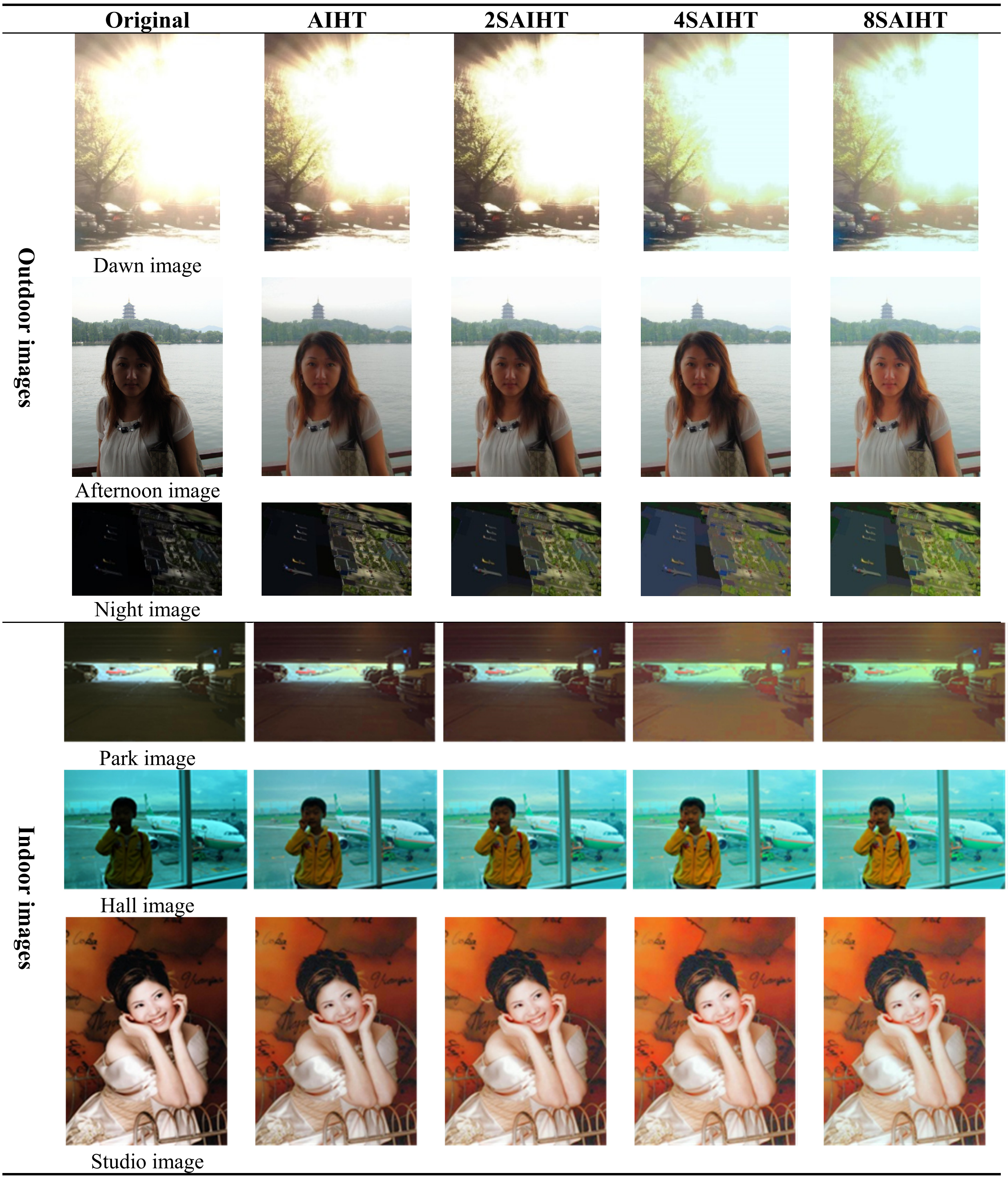
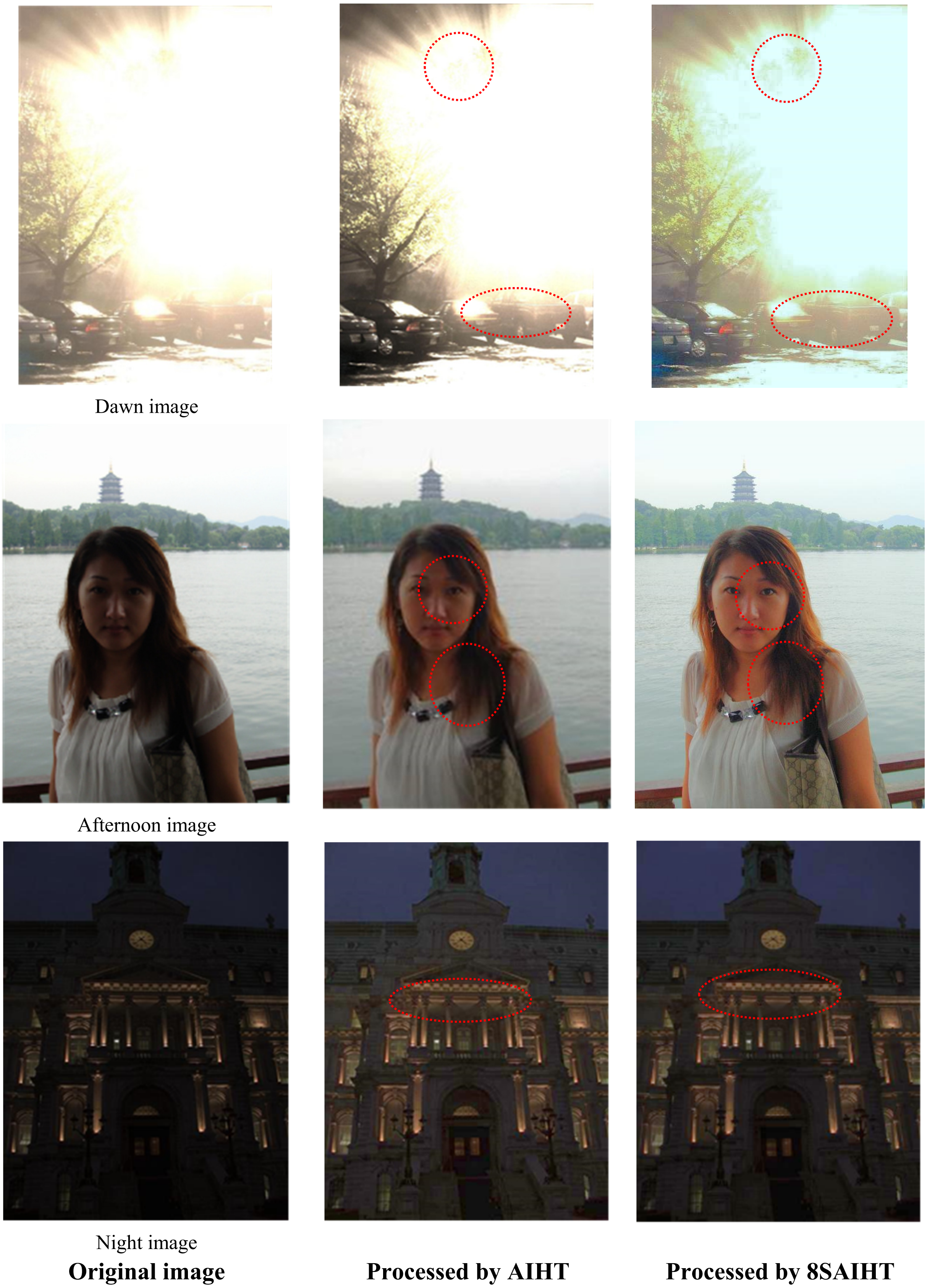


Figure 4. Result comparison of the enhanced image processing by AIHT and 8SAIHT.



For comparison, relative computation times were measured with respect to various scales of MSAIHT (including 2SAIHT, 4SAIHT and 8SAIHT). Table 1 compares the results of various scales of MSAIHT computation time. The more the sub-band number is split, the longer the computation time. Table 2 shows parameter values of various scale of MSAIHT (including 2SAIHT, 4SAIHT and 8SAIHT). It lists *mean*, *variance*, *gain* and *bias* values of sub-band parameters used for the MSAIHT methods (including 2SAIHT, 4SAIHT and 8SAIHT). Table 3 compares results by histogram equalization; contrast limited adaptive histogram equalization and AIHT methods, using the measures of Mean Square Error; MSE, Signal to Noise Ratio; SNR and Peak Signal to Noise Ratio; PSNR. The final results show that the AIHT algorithm is much better than the other two methods. Table 4 compares results by 2SAIHT, 4SAIHT and 8SAIHT methods using the measures of MSE, SNR and PSNR. The experimental results present show not only that 8SAIHT algorithm has the best effect, but also for a variety of different scenarios. In this study the MSAIHT method was better than histogram equalization, contrast limited adaptive histogram equalization and AIHT.

Table 1. Comparison of run-time results of various scales of Multi-Scale AIHT (MSAIHT).

Image Resolution	AIHT	2SAIHT	4SAIHT	8SAIHT
355 × 505	0.056927	0.124237	0.200754	0.377843
376 × 565	0.061338	0.138471	0.222797	0.437374
480 × 640	0.079687	0.169541	0.298019	0.585694
1280 × 800	0.207015	0.493772	0.876402	1.863152
2048 × 1536	0.579902	1.415407	2.514882	5.353876

Table 2. Parameter values of various scales of MSAIHT (including 2SAIHT, 4SAIHT and 8SAIHT).

		AIHT							
		2SAIHT							
		4SAIHT							
		8SAIHT							
		band_1	band_2	band_3	band_4	band_5	band_6	band_7	band_8
Mean	AIHT	0.5582							
	2SAIHT	0.4786	0.5767						
	4SAIHT	0.3933	0.5460	0.5873	0.5492				
	8SAIHT	0.4356	0.4170	0.5297	0.5496	0.5655	0.5889	0.5557	0.5277
Variance	AIHT	0.3483							
	2SAIHT	0.1715	0.1332						
	4SAIHT	0.0593	0.0877	0.0969	0.0451				
	8SAIHT	0.0221	0.0401	0.0487	0.0431	0.0520	0.0377	0.0318	0.0092
bias	AIHT	1.0264							
	2SAIHT	0.6212	0.5474						
	4SAIHT	0.4383	0.5332	0.5603	0.3822				
	8SAIHT	0.4459	0.6006	0.6621	0.6227	0.6843	0.5822	0.5348	0.2883
gain	AIHT	0.9443							
	2SAIHT	0.8318	0.8715						
	4SAIHT	0.7919	0.8596	0.8754	0.8609				
	8SAIHT	0.8124	0.80360	0.85314	0.86102	0.8672	0.87606	0.86342	0.8523

Table 3. Compared results of HE, CLAHE and AIHT methods using Mean Square Error (MSE), Signal to Noise Ratio (SNR) and Peak Signal to Noise Ratio (PSNR).

Image Type	Name	HE			CLAHE			AIHT		
		MSE	SNR	PSNR	MSE	SNR	PSNR	MSE	SNR	PSNR
Outdoor images	Dawn	0.169	5.027	5.913	0.043	10.32	23.143	0.039	22.11	25.89
	Afternoon	0.010	46.39	104.1	0.043	10.32	23.143	0.010	45.10	101.2
	Night	0.167	0.089	5.974	0.060	0.250	16.780	0.017	0.854	57.35
Indoor images	Park	0.059	1.669	17.06	0.034	2.885	29.495	0.003	28.88	295.3
	Hall	0.002	175.2	486.1	0.049	7.323	20.323	0.016	22.14	61.44
	Studio	0.027	12.25	37.01	0.056	5.897	17.825	0.016	21.06	63.64

Table 4. Compare results of 2SAIHT, 3SAIHT, 4SAIHT and 8SAIHT methods using MSE, SNR and PSNR.

Image Type	Name	2SAIHT			4SAIHT			8SAIHT		
		MSE	SNR	PSNR	MSE	SNR	PSNR	MSE	SNR	PSNR
Outdoor images	Dawn	0.029	29.48	34.67	0.005	176.0	207.0	0.006	143.8	169.2
	Afternoon	0.007	61.65	138.3	0.015	29.80	66.85	0.030	15.00	33.65
	Night	0.123	0.122	8.159	0.158	0.094	6.316	0.151	0.099	6.640
Indoor images	Park	0.011	8.610	88.02	0.090	1.085	11.09	0.058	1.691	17.28
	Hall	0.016	22.14	61.44	0.052	6.888	19.11	0.058	6.237	17.31
	Studio	0.016	21.06	63.64	0.079	4.206	12.71	0.076	4.328	13.08

4. Conclusions

Previous work showed that using an AIHT-based image contrast enhancement method has two drawbacks. First, it lacks a mechanism to adjust the degree of enhancement; using the AIHT-based image contrast enhancement approach cannot retain the detail brightness distribution of the original image, thus leading to distortion. Second, this algorithm can only be applied to the image for global contrast enhancement, and cannot achieve local contrast enhancement. It is thus unable to meet the Human Visual System mapping curve, resulting in non-smooth or distorted images.

This study proposes a new, effective multi-scale image enhancement approach based on the adaptive inverse hyperbolic tangent algorithm as a contrast function in order to map from the original image into a transformed image. This algorithm is a simple pixel-wise "AIHT" correction of the input data, by introducing a sub-band processing concept to overcome the wide dynamic range usually required for contrast enhancement, an automatic image based strength correction, and the *bias* and *gain* of sub-band parameters in order to avoid the contrast and color saturation loss common to contrast enhancement methods. This algorithm can improve the displayed quality of contrast in scenes, and offers efficient and fast computation. This approach has two major features: (1) a sub-processing method to achieve the local contrast enhancement; (2) an extreme case images processing method that is capable of enhancing and retaining the details of an original image. Enhanced images will be very helpful for further image analysis processes.

Experimental results show that it is possible to maintain a large portion, if not all, of the perceived contrast of lightness while significantly enhancing the image contrast. The form of these curves used for enhancement was determined based on a simple series of interpolations from a set of optimized reference curves. The proposed algorithm enables a user to correctly identify a target, and to dynamically adjust the parameter by using the multi-scale method. Experimental results also show that the new algorithm can adaptively enhance image contrast, and that it produces better visual quality than AIHT, histogram equalization or contrast limited adaptive histogram equalization. In addition, it can also be implemented in real-time in various monitor systems. For overexposed and underexposed images, the proposed algorithm also significantly improves contrast enhancement, with no effects resulting from environments. It is our belief that these functions will play a crucial role in developing a more universal approach to color gamut mapping.

Author Contributions

In this study, an Eight-Scale Adaptive Inverse Hyperbolic Tangent (8SAIHT) method is proposed to enhance the contrast of an image. All the authors contributed to the content of this paper. The 8SAIHT coefficient parameter adjustments can provide a further local refinement in detail under the AIHT algorithm, and uses the sub-band to calculate the local mean and local variance before the AIHT algorithm is applied. This approach is convenient and effective in the enhancement processes for various types of images. It is also capable of adaptively enhancing the local contrast of the original image while simultaneously extruding more on object details. The experimental results present show not only that 8SAIHT algorithm has the best effect, but also for a variety of different scenarios. The 8SAIHT method was better than histogram equalization; contrast limited adaptive histogram equalization and AIHT.

Conflicts of Interest

The authors declare no conflict of interests.

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