Dark Image Enhancement through Intensity Channel Division and Region Channels using Savitzky-Golay Filter

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Abstract— Principal objective of image enhancement is to process an image so that result is more suitable than original image for specific application. Digital image enhancement techniques provide a multitude of choices for improving the visual quality of images.

The existing contrast enhancement algorithms such as local, global, partial, bright and dark contrast stretching, Adaptive HE techniques occasionally result in artifacts such as halo effects in sharp boundaries or noise effects and also over enhancement which results a spurious details of the image and unnatural effects in the processed images. These drawbacks increase for images taken under poor illumination conditions.

To overcome these drawbacks we propose an algorithm that enhances dark images, sharpens edges, reveals details in textured regions, and preserves the smoothness of flat regions. In this paper we enhance the image contrast based on Intensity Channel Division and Region Channels. We analyze the contrast of the image in the boundary and textured regions, and group the information with common characteristics. These groups model the relations within the image, from which we extract the transformation functions.

We propose to mix the channels with similar characteristics in to region channels. The proposed method is robust because it adapts its transformation function which is Savitzky Golay filtered, to the contents of the image, which avoids the introduction of errors in the image. The mixture of different region channels also increases the quality of the output because it allows a distinct enhancement for different parts of the image. This process avoids over enhancement problems in areas with normal dynamic ranges.

Index Terms—*Artifacts; Channel Division; Region Channels; Savitzky Golay filter; Curve-fitting Toolbox;*

I. Introduction

Contrast enhancement is necessary to improve sub-standards that are captured in bright or dark environments produce low contrast images .Several algorithms have been proposed to overcome this problem. One of the widely used technique is Histogram Equalization (HE) which enhances the intensity of the image but in addition to this artifacts are produced in smooth regions and does not consider the boundaries which lowers the sharpness of the image .Another approach is Adaptive Histogram Equalization (AHE) provides the contrast enhancement of the image but over enhancement and unnatural images are produced to overcome this problems we go for enhancing the content of the image.

The first step in the proposed algorithm is the intensity pair distribution. In this algorithm the global properties of HE [3] and local properties of AHE are combined. Here the contrast pairs are formed and the transformation is generated. The obtained output image has artifacts so we go for intensity channel division and the transformation function for this is generated but channel division is not sufficient to produce the enhanced image so we group this intensity channels to region channels and the transformation function is generated to get the enhanced image.

II. Enhancement through Channel Division Approach

Based on the information extracted from the boundaries and textured regions the proposed algorithm form the adhoc transformation. Here we form the contrast pairs using the contrast which gives the relation between two neighboring pixels. There may be isolated pixels which does not form neighbor with the other pixel so we pileup the contrast pairs in to the Local Contrast Indicator (LCI) function and fuse such functions in to channels to minimize the artifacts. This is a process known as channel division. This channel division is used to spread the inaccurate dynamic range and it can control the interference & overlap of the contrast pairs. We then fuse this channel division in to region channels. The region channels work to enhance the characteristics of image and fuse that results to reduce artifacts and provide maximum enhancement that results to reduce artifacts and provide maximum enhancement that results to reduce artifacts and provide maximum enhancement. The transformation function for the region is formed and we apply SGolay filter to the transformation function to remove the noise.

To carry out the proposed algorithm first we transform the image in to HSV color space which is Hue-Saturation-Value. Next we apply the proposed algorithm to the V component that is illumination component of the image where the H & S are retained. Later the preserved H & S are fused with the enhanced V component to provide enhanced image.

A. Contrast Pair Distribution

In our algorithm first the intensity pair distribution is formed by extracting both local and global information of the

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image. [2] For a given image the intensity difference is found out between the center pixel and neighboring 8 pixels.

The contrast pair ρ^{i}_{j} between two given intensities *i* and *j* is formed as a set of votes for every intensity in the intensity set *(i,……,j)*. We define the set of contrast pairs for a pixel *(x, y)* as

$$P(x,y)=\left\{\rho^{I(x',y')}_{I(x,y)} \middle| (x',y')\in N(x,y)\right\} \qquad (1)$$

where *N(x,y)* is a set representing 8 neighbours of the center pixel *(x,y).*

The first four contrast pairs are formed by scanning the three neighbors above the pixel and the one directly to its left. And the other four pairs are formed by scanning the three neighbors below and the one to its right.

The set of contrast pairs of each image is divided into two classes: edge [8] and smooth. If the intensity difference between the pair intensities exceeds the threshold (10 intensity levels in our process) then it is considered an edge contrast pair, otherwise it is considered as smooth contrast pair.

To create the transformation function we use LCI of the contrast pairs. We use the LCI which is normalized since we found that channel division provides higher enhancement than the proposed method. The LCI is formed by grouping the votes formed by the contrast pairs [2]. Here we use an edge contrast pair which reveals the details of the image. This procedure preserves the flat regions. As a result the accumulation of all the edge contrast pairs generates an LCI function *f*, defined by

$$f(i)=\sum_{x,y}\ \sum_{\rho\ \in P_e(x,y)} \rho(i) \qquad (2)$$

where *f(i)* is the i^{th} position of the LCI *f*, which acts like a vector of the accumulated votes from the contrast pairs, *x* and *y* are coordinates of the image, $P_e(x, y)$ is the set of neighboring edge contrast pairs for pixel *(x, y)*, *ρ(i)* is the i^{th} position in an edge contrast pair of *(x, y)*, i is the intensity index in the range $0 \le i \le N$, and *N* is the maximum number of intensities. Note that, for simplicity, the intensities have been removed from the contrast pair notation for pairs that are identifiable. Furthermore, the edge contrast pairs for the pixel *(x, y)*, i.e., $P_e(x, y)$, are defined by

$$P(x,y)=\left\{\rho^{I(x',y')}_{I(x,y)} \middle| (x',y')\in N(x,y) \wedge \left|I(x,y)-I(x',y')\right|\ge\varepsilon \right\} \qquad (3)$$

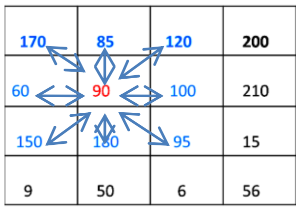
where *(x, y)* and *(x′, y′)* are the positions of the pixels in the image with intensities *I(x , y)* and *I(x′, y′)*, *N (x , y)* contains the eight neighbors of *(x , y)*, and *ε* is a constant. Once the LCI is computed, it is integrated and normalized by

$$F(k)=\frac{\sum_{i=0}^{k} f(i)}{\sum_{i=0}^{N} f(i)} \qquad (4)$$

where *F(k)* is the k^{th} position in the integrated expansion force *F*, *f(i)* is the i^{th} position in the LCI *f*, *k* is the intensity index in the range $0 \le k \le N$, and *N* is the maximum number of intensities. Since the transformation function should be monotonically increasing and single-valued, we normalize and project the transformation function *T* onto the identity transformation *I*, which is defined by *I(x)=x /N* for $0\le x \le N$. Then the transformation function can be defined by

$$T(k)=\frac{I(k)+F(k)}{\max(I+F)} \qquad 0\le k\le N \qquad (5)$$

This process is well understood with an example showing a sub image with some pixel values as shown in Fig. 1.



Intensity Pairs formed are:

(90,170) (90, 85) (90,120) (90, 60)

(90,100) (90,150) (90,180) (90, 95)

Figure 1: Sub image & 8 Neighbours with 8 intensity pairs

1) *Formation Of Expansion Force*

If the Intensity difference of an Intensity Pair is larger than a pre-selected threshold (10), train of *Expansion Forces* is generated. From the example considered some Expansion forces (difference >10): (90,170), (90, 120)

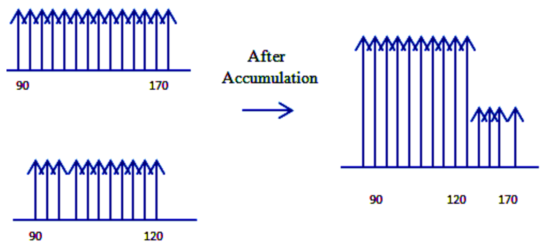


Figure 2: Expansion Forces

Voting between 90,170 and 90,120 are shown as impulses with magnitude one if difference is greater than 10 otherwise zero and after accumulation or integration the net expansion force values are shown as impulses with magnitude 2 between intensity values 90,120 and magnitude 1, between 120, 170 as shown in Figure 2.

B. *Formation of Intensity channels*

In intensity pair distribution, the contrast pairs belong to different regions. Thus, one accumulation of contrast pairs does not represent the intensity relations and may separate the intensities that should stay together. To overcome this problem

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we group the contrast pairs into intensity channels and the transformation obtained from the intensity channels gives better result than the intensity pair distribution because the LCI of each channel affects only its peers. Hence the intensity channels avoid the interference of LCI's that excessively spread the intensities of the group, and consequently compress other intensities [2]. This intensity channels maintains the flat regions in the image and enhance the textured regions, which avoids the introduction of artifacts.

The intensity channel LCI, $f^{i}(j)$, for the intensity i is defined by

$$f^{i}(j) = \sum_{x,y} \sum_{\rho \in P^{i}e(x,y)} \rho(j) \qquad (6)$$

where $f^{i}(j)$ is the j^{th} position in the LCI f^{i}, x and y are coordinates of the image, $P^{i}_{e}(x, y)$ is the set of the eight neighboring edge contrast pairs for the pixel (x, y) such that the intensity i is within that pair's intensity, and $\rho(j)$ is the j^{th} position in an edge contrast pair of (x, y). Note that i and j vary from zero to the maximum number of intensity levels, i.e., N. Furthermore, the set of edge contrast pairs for the pixel (x, y) and intensity i, P^{i}_{e}, is defined by

$$P^{i}_{e}(x,y) = \left\{ \begin{array}{l} \rho^{I(x',y')}_{I(x,y)} \big| (x',y') \in N(x,y) \\ \wedge \big| I(x,y) - I(x',y') \geq \varepsilon \\ \wedge (i = I(x,y \vee i) = I(x',y') \big| \end{array} \right\} \qquad (7)$$

where (x, y) and (x', y') are the positions of the pixels in the image with intensities $I(x, y)$ and $I(x', y')$, respectively, $N(x, y)$ contains the eight neighbors of (x, y), and ε is a constant. Finally, the accumulation for each intensity channel LCI, F^{i}, is computed as in (4), and their transformation functions, T^{i}, are projected as in (5), by replacing f with f^{i}, as follows:

$$F^{i}(k) = \frac{\sum_{j=0}^{k} f^{i}(j)}{\sum_{j=0}^{N} f^{i}(j)} \qquad (8)$$

$$T^{i}(k) = \frac{I(k) + F^{i}(k)}{\max(I + F^{i})} \quad 0 \leq k \leq N \qquad (9)$$

C. Region channels

Grouping the contrast pairs in to intensity channels is not sufficient to produce the best enhancement, as there may be intensity channels with similar properties so we mix the channels with similar characteristics in to region channels [1].

$$T_{r} = \frac{\sum_{i=I^{r}\min}^{I^{r}\max} T^{i}}{I^{r}\max - I^{r}\min + 1} \quad 1 \leq r \leq R \qquad (10)$$

where T^{r} is the r^{th} region channel transformation, T^{i} is the transformation function for each intensity channel i, and $I^{r}min$ and $I^{r}max$ are the lower and upper bound (intensities) for the r^{th} region channel

We divide the intensity channels in to three regions namely dark, middle & bright intensities. We produce the transformation function for three regions that spreads intensities. The obtained results are grouped using weighting functions to create final image. The enhanced image is mixture of region channels each channel has different weighting function that emphasizes its characteristics. The final transformation is given by

$$\xi(i) = \sum_{r=1}^{R} \omega_{r}(i).T_{r}(i) \qquad (11)$$

where ω_{r} is the weighting function for the r^{th} region channel, and $T_{r}(i)$ indicates the i^{th} position in the r^{th} region channel transformation function.

Here the weighting functions are the shifted Gaussian functions shown in the Figure 3.

Finally, the image is enhanced by

$$I_{e}(x,y) = \xi(I(x,y)) \qquad (12)$$

where $I(x, y)$ is the intensity of the pixel (x, y) in the original image, ξ is the final transformation function after smoothing using SGolay filtering(Curve Fitting Toolbox in MATLAB) , and I_{e} is the enhanced image.

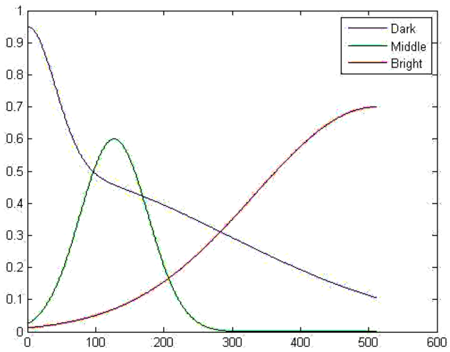

Figure 3: Weighting Shifted Gaussian Functions

III. SAVITZKY GOLAY FILTERING (CURVE FITTING TOOLBOX IN MATLAB)

Savitzky-Golay filtering can be thought of as a generalized moving average [5]. We derive the filter coefficients by performing an un-weighted linear least-squares fit using a polynomial of a given degree. For this reason, a Savitzky-Golay filter is also called a digital smoothing polynomial filter or a least-squares smoothing filter. Note that a higher degree polynomial makes it possible to achieve a high level of smoothing without attenuation of data features.

The Savitzky-Golay filtering method [6] is often used with frequency data or with spectroscopic (peak) data. For frequency data, the method is effective at preserving the high-frequency components of the signal. For spectroscopic data, the method is effective at preserving higher moments of the peak such as the line width. By comparison, the moving average filter tends to filter out a significant portion of the signal's high- frequency content, and it can only preserve the lower moments of a peak such as the centroid. However, Savitzky-Golay filtering can be less successful than a moving average filter at rejecting noise. The Savitzky-Golay smoothing method used by Curve Fitting Toolbox software follows these rules:

i. The span must be odd.

ii. The polynomial degree must be less than the span

iii. The data points are not required to have uniform spacing

Normally, Savitzky-Golay filtering requires uniform spacing of the predictor data. However, the Curve Fitting Toolbox algorithm supports non uniform spacing. Therefore, we are not required to perform an additional filtering step to create data with uniform spacing. We can use the smooth function to smooth response data [5]. We can also use optional methods for moving average, Savitzky-Golay filters, and local regression with and without weights and robustness (lowess, loess, rlowess and rloess). The syntax of the smoothing methods is presented below:

Syntax [7]

```
yy = smooth(y,span)
yy = smooth(y,method)
yy = smooth(y,span,method)
yy = smooth(y,'sgolay',degree)
yy = smooth(y,span,'sgolay',degree)
```

IV. Quantitative and Qualitative Analysis

A. Quantitative Measures

To evaluate the image, we use three different metrics: measure of enhancement by entropy, structural similarity. The structural similarity metric was an alternative to intensity based metrics. The structural similarity is based on the assumptions that natural images are highly structured, since their pixels exhibit strong dependencies, and that the human visual system is highly optimized to recover the structural information from an image. We estimate the luminance of the image as the mean intensity such that

$$\mu_I = \frac{1}{N}\sum_{x,y} I(x,y) \qquad (13)$$

where N is the number of pixels in the image and $I(x, y)$ is the intensity at the position of the pixel (x, y). Instead of using the correlation proposed by Wang et al., we use the ratio of the original image luminance to that of the enhanced image. This process allows us to identify the differences in images, given that the enhanced image should be brighter than the original, and simultaneously determine the structural Similarities between the images. Note that the definition by Wang et al. measures only the similarity to the dark image.

Thus, we define the luminance index by the ratio

$$L(I_o, I_e) = \frac{\mu_{Ie}}{\mu_{Io}} \qquad (14)$$

where I_o is the original image, I_e is the enhanced image, and estimate the contrast as the standard deviation of the image, given by

$$\sigma_1 = \sqrt{\frac{1}{N-1}\sum_{x,y}(I(x,y)-\mu_I)^2} \qquad (15)$$

Similar to the luminance index, we use the ratio of the contrast of the original image to that of the enhanced image. Hence, the contrast index is defined by

$$c(I_o, I_e) = \frac{\sigma_{Ie}}{\sigma_{Io}} \qquad (16)$$

Likewise, the structural index is given by the correlation coefficient, which is defined as

$$S(I_o, I_e) = \frac{\sigma_{Io,Ie} + K}{\sigma_{Ie}\sigma_{Io} + K} \qquad (17)$$

where K is a constant to avoid division by zero, and $\sigma_{Io,Ie}$ is

$$\sigma_{Io,Ie} = \frac{1}{N-1}\sum_{x,y}(I_o(x,y)-\mu I_o)(I_e(x,y)-\mu I_e) \qquad (18)$$

where N is the number of pixels of the images, and $I_o(x,y)$ and $I_e(x,y)$ are the intensities in the (x, y) position of each image. For our evaluation, we do not mix these indices as Wang et al. proposed [2]. Instead, we analyze them separately, which allows us to do a deeper analysis on the enhancement of each image.

B. Qualitative Measures

The enhanced images are for human visual perception. There are four different categories which are given to the observers to evaluate the image.

*1) Similarity:*This refers to the similarity between enhanced image and original image. The question was phrased as : “Which enhanced image is most similar to or better than the original?”

*2) Edge details:*This refers to the amount of detail perceived in the enhanced image. It describes how many details the enhancement algorithm preserves and/or reveals from the original image. The question was phrased as: “which enhanced image reveals more of the original image’s details?”

3) Color and Tonal Rendition: This characteristic refers to any improvements in the colors and tones of the enhanced images with respect to the original. The question was phrased as: “Which enhanced image presents better colors and tones with respect to the original?”

4) Artifacts: This characteristic refers to the robustness of the algorithm against the creation of artifacts. It is used to measure the artifacts created by the enhancement algorithm. The question was phrased as: "Which enhanced image presents fewer artifacts?"

V. RESULTS

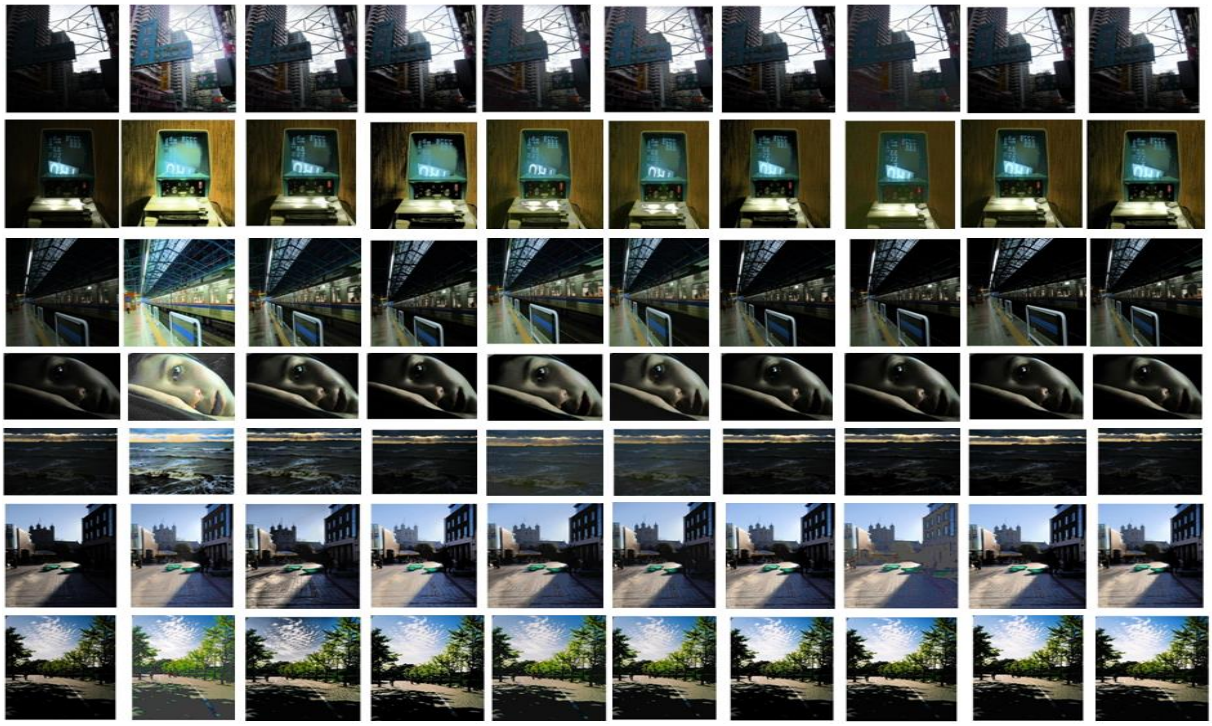

Figure 4: Images from top to bottom:"advertisement","atm","subway","girl","ocean","street1","street2". a)Input image b) Result of HE c) Result of AHE d)Result of Intensity Pair Distribution e) Result of Channel Division with Moving Average filter f) Result of Channel Division with SGolay filter g)Result of Region Channels with Moving Average filter h) Result of Region Channels with Rlowess filter i) Result of Region Channels with Lowess filter j) Result of Region Channels with SGolay filter

Fig. 4 show the outputs of different alternative methods which are compared to proposed method. The methods compared here are HE, AHE, Intensity Pair Distribution, Channel Division using Moving Average filter and SGolay filter & Region Channels using Moving , Rlowess, Lowess & SGolay filters. The images used here are "advertisement", "atm", "subway", "girl", "dark ocean", "street1" and "street2".

The methods other than the proposed method have drawbacks in them such as over enhancement, artifacts, unnatural images, lowered boundaries sharpness etc. To overcome this we used our proposed algorithm which gives the enhanced image compared to previous methods. From the above outputs we observe that our proposed method is best

Quantitative and Qualitative Measures report

The Luminance Index for the result of HE for all the images considered is more compared to other methods. It is because of over enhancement which is a limitation for that method. Thus, we used two additional metrics, the Structural Similarity Index and Contrast pair-based metric, to evaluate the enhancement. Considering our proposed metric, it scored better in the "Girl," and "Street" images. It revealed details in the shadow areas, as shown in the face of the girl an image for which other methods scored poorly in the contrast pair-based metric, and had poor balance in the structural similarity indices. Additionally, the algorithm was able to maintain the smoothness in the regions of the face and the background. Moreover the proposed method was able to recover details in mixed images as well. For example, the "Street" image had a shadow due to a building that hid some of the details in the image, but other areas in the image were well exposed. The proposed method was able to reveal the details near the building and maintain the details in other parts of the image because it created different transformation functions. This behavior is verified in the balance of the luminance, contrast, and structural indices – all of which exhibited high scores for the proposed method.

Overall, the proposed method did a better job in producing images with means closer to ideal images—i.e., points closer to the diagonal in the space defined by the edge and smooth means. Furthermore, the structural similarity indices reveal that the proposed method procured

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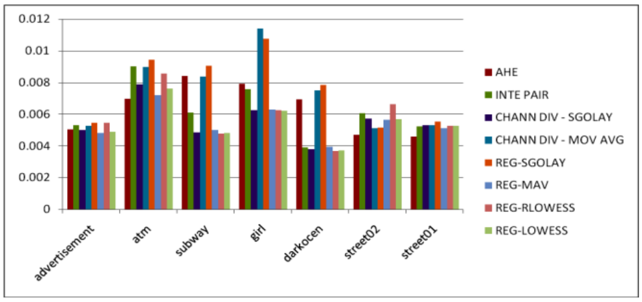
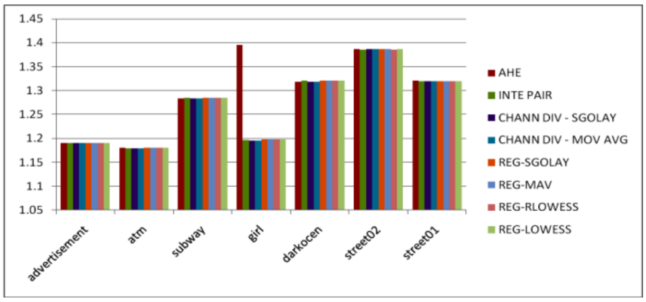
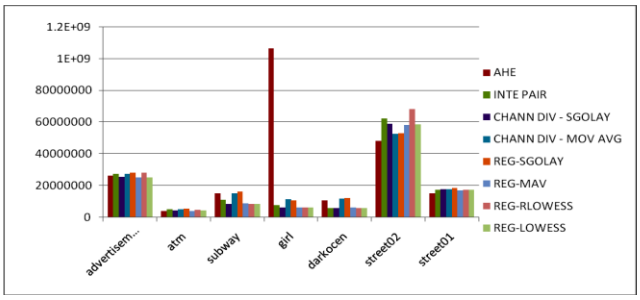
good luminance and contrast indices while maintaining the structural index the proposed method maintained the image's structure during the enhancement process and simultaneously increased the luminance and the contrast more than other methods.



a)

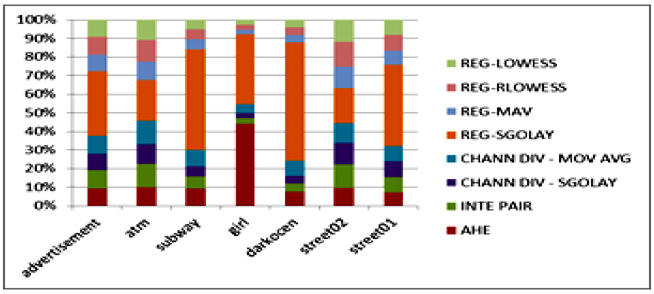


b)

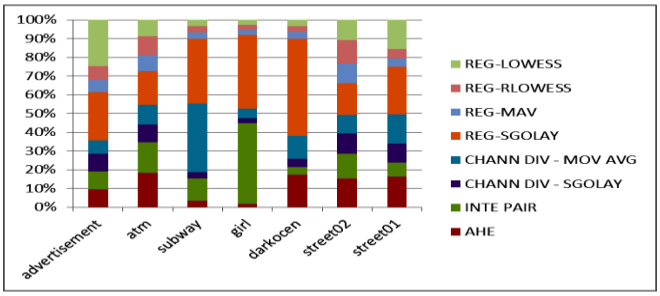


c)

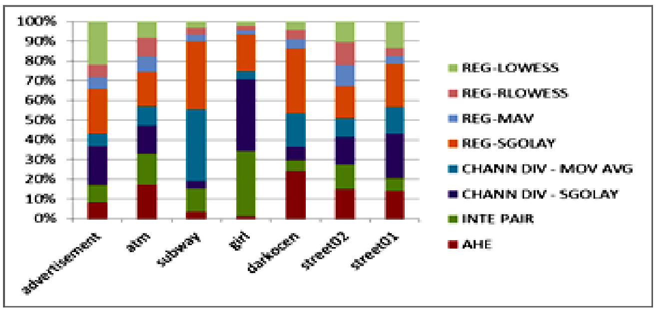
Figure 5: Structural Similarity Indices (SSI) of the results from different image enhancement methods a) Luminance Index b) Contrast Index c) Structural Index



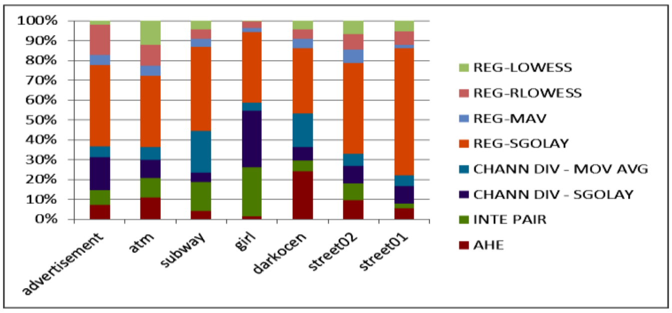
a)



b)



c)



d)

Figure 6: Percentage of evaluators who preferred each image according to (a) similarity (b) edge details (c) color and tonal rendition and (d) presence of fewer artifacts

Moreover, the proposed method outperformed the intensity pair algorithm, which produced below par results, as revealed by the contrast pair-based metric and the structural similarity indices as shown in Fig. 5. Unfortunately, enhancement errors in the HE introduced peaks in the luminance and contrast indices, but kept the structural index low in comparison to other methods. Finally, we performed a subjective evaluation of the methods to better assess their performances. For each set of images and for each category, the evaluators were asked to select the result that best exemplified their opinions. They were not informed of the methods that produced each result, and the images were presented in random order. The results of opinions are shown in Fig. 6 and observed that Region Channels method with SGolay filtering was made as a best choice for image enhancement.

VI. Conclusion

In this paper, we introduced a content-aware enhancement algorithm that can enhance images from different environments. The algorithm creates different enhancement functions based on the contents of the image, thereby improving its enhancement capabilities while reducing the artifacts and other unnatural effects in the resulting images. The method analyzes the contents through contrast pairs, which are grouped together according to their intensities. Ideally this process increases the enhancement and level of revealed. Ultimately the enhancement is intended to mimic the human visual perception, which is accomplished by adaptively combining different region channels. This mixture allows us to enhance some characteristics, such as the details in dark and bright regions and preserves smooth and flat regions.

The proposed method is robust because it adapts its transformation functions to the contents of the image, which avoids the introduction of errors in the image. The mixture of different region channels also increases the quality of the output because it allows a distinct enhancement for different parts of the image. This process avoids over enhancement problems in areas with normal dynamic ranges.

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