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# Color Enhancement in Images with Single CCD camera in Night Vision Environment

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**Abstract**: In this paper, we describe an effective method to enhance the color night images with spatio-temporal multi-scale retinex focused to the Intelligent Transportation System (ITS) applications such as in the single CCD based Electronic Toll Collection System (ETCS). The basic spatial retinex is known to provide color constancy while effectively removing local shades. However, it is relatively ineffective in night vision enhancement. Our proposed method, STMSR, exploits the iterative time averaging of image sequences to suppress the noise in consideration of the moving vehicles in image frame. In the STMSR method, the spatial term makes the dark images distinguishable and preserves the color information day and night while the temporal term reduces the noise effect for sharper and clearer reconstruction of the contents in each image frame. We show through representative simulations that incorporating both terms in the modeling produces the output sequential images visually more pleasing than the original dim images.

## 1. Introduction

The quality of sequential images captured from a CCD camera directly affects the performance of the post processing objectives such as pattern recognition or classification to acquire interesting objects or region. In the ITS application such as ETCS and traffic surveillance, the key objective is to detect and count the number of vehicles in each image frame. However, the image quality of a single CCD camera is also sensitive to the surrounding light sources such as the sun during day times and the lighting of street lamps or headlights at night. As a result, the performance of various tracking/monitoring systems is poor in the case of adverse lighting condition. To overcome this problem, alternate sensors independent of light sources are employed. For example, infrared sensor [1] which seeks the source's heat for discernment and loop detector that monitors the weight of objects – were added in the listing of alternate sensors to support the traffic monitoring system. In military, a means of fusing registered low-light visible and thermal infrared imagery is employed [2] for night vision. Recent night vision devices are known to provide the ability to judge the depth of depressions and closing distance to other nearby vehicles under poor visibility conditions and at night [3]. In this case, the production cost of the fusion system rises extremely high in comparison with that of the sole camera based system. Thus the sole CCD camera based vision system has the advantage with respect to cost if satisfactory image quality can be attained in twilight and at night.

The main focus of this paper is to enhance the sequential images captured with a normal CCD camera by employing the spatio-temporal multi-scale retinex (STMSR) scheme. This is considered as a preprocessing procedure to obtain improved end-user results. To make the system independent of illumination, the basic retinex scheme proposed by Land [4] is adopted and modified. The basic retinex is known to be robust to illumination variant situations but is a spatial only filtering algorithm disregarding the temporal aspect. There are many types of noise present in night images due to insufficient light environment and cheap equipment. As a result of applying the basic retinex, the output image becomes more vivid and brighter than the dim original as can be shown in Figures 1-(a) and 1-(b), respectively. However, the presence of noise as shown in Figure 1-(b) is so detrimental that it causes a direct degradation in system performance. Since the spatial retinex alone is not as robust to noise, a separate noise filtering employing temporal information is exploited to further suppress the noise.

This paper is organized as follows. In Section 2, the proposed spatio-temporal filter STMSR is described. The representative experimental results are provided in Section 3. Section 4 presents our concluding remarks.

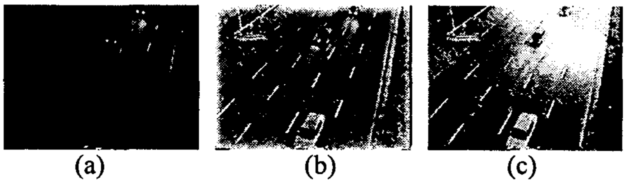
(a) (b) (c)

Figure 1. (a) Color image captured on road at night. (b) Basic retinex was applied to original image. (c) Histogram equalization was applied to original image. Image has lost the color information

## 2. Spatio-Temporal Multi-Scale Retinex(STMSR)

While the spatial MSR procedure is capable of enhancing the night vision, it also produces the speckle noise that directly leads the system to poor performance. One of the possible ways to suppress this noise is to incorporate the temporal processing, thereby considering the image's temporal changes. Since the speckle noise occurs randomly, a spatial filter (e.g. low-pass filter) alone can not effectively suppress the noise. A blind use of low-pass filter also tends to blur the output images. In designing the intended temporal procedure, however, the integrity of moving objects in the sequential images needs to be maintained. The time differential method is employed to detect the moving objects. With this base, the temporal term is designed in the form of an iterative weighting summation. We discuss the spatial MSR procedure and then use the result to further the enhancement that includes the temporal information in the temporal MSR as follows.

### 2.1 Spatial Multi-Scale Retinex

The practical implementation of the retinex, which is essentially a center/surround method, is designed by Jobson [5]. A single-scale retinex is extended to a multi-scale method that achieves simultaneous dynamic range compression, color consistency, lightness rendition, and to produce results that compare favorably with human visual perception [6].

The single-scale retinex is defined by

$$R_i(x,y,t) = \log I_i(x,y,t) - \log[F(x,y) * I_i(x,y,t)] \qquad (1)$$

where $R_i$ is the SSR output,

$I_i(x,y,t)$ is the image distribution or color level in the $i$ th color band consists of 3 bands - red, green, blue,
"*" denotes convolution,
$x, y$ are 2-D spatial positions,
$t$ is temporal term,

$F(x,y)$ is a exponential surround function given by

$$F(x,y) = \exp[-(x^2 + y^2)/c^2] \qquad (2)$$

where the term " $c$ " is analogous to the range of scale. The constraint of surround function is

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} F(x,y)dxdy = 1 \qquad (3)$$

In night vision, the magnitude of scale determines the type of information that the retinex provides (e.g. smaller scales reconstruct more distinguishable vision but lose some color information in the form of dynamic range compression, and larger scales reconstruct more vivid color information but not the bright vision as in color rendition).

The multi-scale retinex is then a weighted sum of the several different scale retinex as follows.

$$R_{MSRi}(x,y,t) = \sum_{n=1}^{N} w_n R_{ni}(x,y,t) \qquad (4)$$

where $R_{MSRi}$ is the MSR output, $N$ is the number of scales, and $w_n$ is the weight relative to the $n$ th scale. In the experiments conducted, we used three scales of $c$ – small, large, and intermediate ranges. The small scale is weighted higher than others, because it make the night image more distinguishable. In this paper, the only reason the violation of the gray-world assumption [7] was not considered is that the majority of images used was of gray tone road.

### 2.2 Temporal Processing of STMSR

The STMSR procedure can be simply summarized as

$$S_i(x,y,t) = \sum_{k=1}^{K} w_k' R_{MSRi}(x,y,t-k) \qquad (5)$$

where $S_i$ is the $i$ th STMSR output, $t-k$ is the $k$ th past frame among sequential images, and $w_k'$ is the weight relative to temporal factor with $\sum_{k=1}^{K} w_k' = 1$. The temporal procedure is employed not only to restrain the noise in night images but also to make the images more vivid. Above all, the important point about the term $R_{MSRi}$ in Equation (5) is that the moving objects and background must be handled separately as shown in Figure 2.

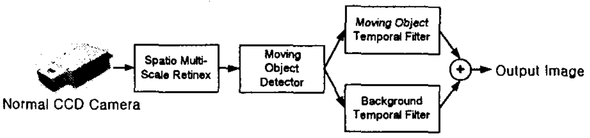

Figure 2. The summary block diagram of night image enhancement system.

For detecting the moving objects from sequential images, we employed the time differential method [8]. This method is so simple that the calculation load is very economical and that this feature is desirable for real time application in the case of stationary camera. Time differential method essentially seeks out the moving objects using the absolute difference between consecutive video frames as described by the equation below:

$$\alpha = | R_i(t) - R_i'(t-1) | \begin{cases} \alpha \geq \text{Threshold} & \Rightarrow \alpha = 1 \\ \text{Otherwise} & \Rightarrow \alpha = 0 \end{cases} \qquad (6)$$

where $\alpha$ is the binary value depends on threshold. This equation attempts to force the input image to take one of the two values of the binarized image. There are many types of noise in binarized output image because the spatial retinex intensifies the potential noise in input image as dynamic range compression. The morphology filter such as "Close" can reduce the spot noise and the remainder of the noise still not removed is left out in the rate calculation of occupation in the entire image. After these procedures, we obtain the separated output image similar to a mask. We perform the "AND" operation between the mask and the sequential spatial MSR output. With this procedure, the image is finally divided into the moving object region and background region. Denoting the moving object region as $Rg_M$ and the background region as $Rg_B$, we combine both terms to build the STMSR output as:

$$R_i'(t) = w_1' Rg_B(t) + w_2' Rg_B(t-1) + Rg_M(t)$$
$$\text{where} \qquad w_1' + w_2' = 1 \qquad (7)$$

The output of Equation (7), $R_i'(t)$, is then reused as $R'(t-1)$ in Equation (6) at the next iteration as shown in Figure 3. After the K-th iteration in Equation (5), $R_i'(t)$ in Equation (7) becomes the output image $S_i(t)$. As a result, this iterative form reduces the speckle noise by the accumulation of past images accordingly.

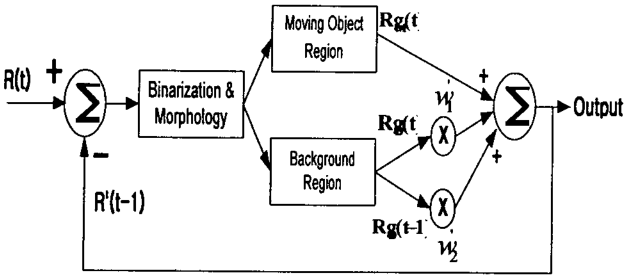

Figure 3. The block diagram shows the iterative temporal processing of STMSR.

## 3. Experimental Results

The performance of STMSR was tested on three sequential images. "Night Road Vision I" comprises a sequence of 86 images. On the right side of the road, there is one yellow color street lamp while the other side is dim as shown in Figure 4-(a). "Night Road Vision II" comprises a sequence of 75 images. These images are a little brighter than "Night Road Vision I" but the light of building makes the tree shadows on the left side of road as shown in Figure 5-(a). Finally, "Day Road Vision" comprises a sequence of 35 images as shown in Figure 6-(a). All sequential images used in experiments were photographed with a normal color CCD (SHC-411NA) during both day and night. Therefore, the image quality is not as good especially those taken at night. Relatively small size noise can be found with a close inspection of the original dim image, particularly in the vicinity of the dark background region such as the road. After undergoing the spatial MSR, the dark images were brightened without losing color information but also produced noise as shown in Figures 4-(b) and 5-(b). The same noise leads the system to poor performance. At the final output images shown in Figures 4-(c) and 5-(c), the noise is effectively suppressed by the temporal procedure of STMSR. The experimental result of "Day Road Vision" as shown in Figure 6 also shows that the STMSR can be employed during day as well as during night in spite of the gray world violation.

To evaluate the performance, we define the mean square error (MSE) as follows:

$$MSE = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{3}\sum_{i=1}^{3}\sum_{X,Y}[S_i(x,y,t) - S_i(x,y,t-1)]^2 \qquad (6)$$

where $i$ is the three band, and $X,Y$ are width and height of a image, respectively. In this paper, MSE implies the average of difference between two sequential images for $T$ images. The major reasons on the presence of this difference are noise, moving objects, and shaky camera at each image. Table I shows the MSE of each Vision for comparison. As shown in Table 1, the original images – "Night Road Vision I", "Night Road Vision II" - show the lowest MSEs because the overall region of images is just too dark to prevent the separation between the two sequential images. The MSEs of STMSR is lower than that of Spatial MSR, because of the ensued noise reduction. In "Day Road Vision", there is a small difference between the MSEs. As such, STMSR exhibits good performance in night vision and these results can be helpful in producing more accurate

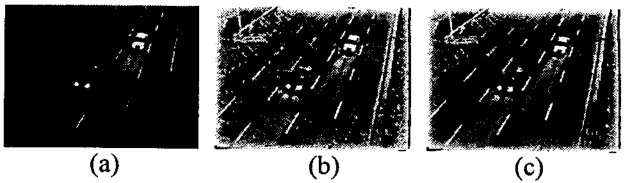
(a) (b) (c)

Figure 4. (a) The 20th image of original 86 sequential images (Night Road Vision I).
(b) Image after spatial MSR. (c) Final output after STMSR.

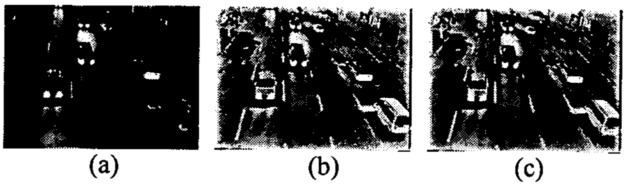
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Figure 5. (a) The 9th image of original 75 sequential images (Night Road Vision II).
(b) Image after spatial MSR. (c) Final output after STMSR.

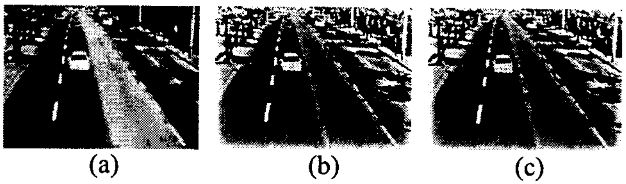
(a) (b) (c)

Figure 6. (a) The 9th image of original 35 sequential images (Day Road Vision).
(b) Image after spatial MSR. (c) Final output after STMSR.

Table 1. Comparison of MSE

| MSE | Night Road Vision I | Night Road Vision II | Day Road Vision |
|---|---|---|---|
| Original | 192.50 | 368.20 | 168.92 |
| Spatial MSR | 1,340.70 | 1,587.60 | 302.70 |
| STMSR | 441.27 | 787.20 | 211.70 |

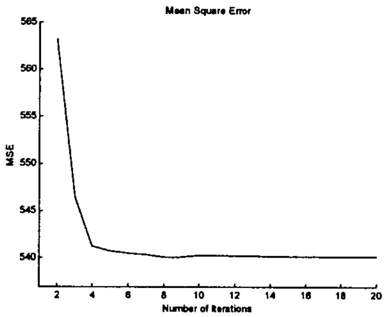

Figure 7. Number of iterations in STMSR as mean square error .

post-processing objectives. The STMSR employed uses past images iteratively as indicated by Equation 5. The number of iteration, $K$, is related to the MSE performance as shown in Figure 7. MSE remains constant as the number of iteration is increased further. The number of iteration that has attained to the pertinent level can not further improve the system performance. Consequently, the experiments presented in this paper came to the iteration number of $K=6$ as the best performing condition. Figure 8 shows other similar experimental results of the proposed STMSR procedure.

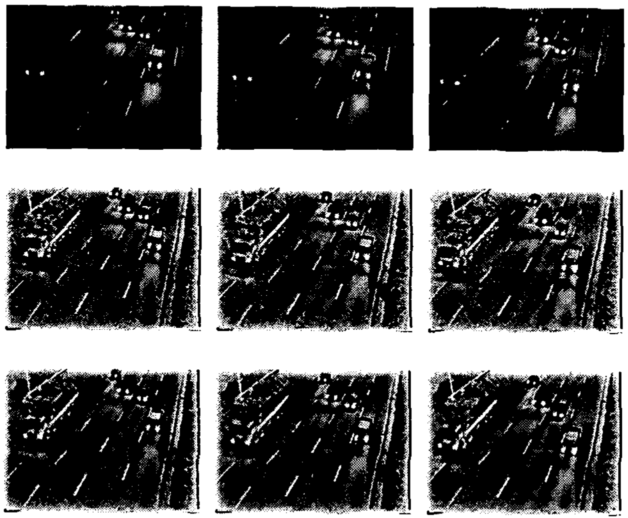

Figure 8. Each column is 80th , 83th, 86th image, respectively. Each row is original image, spatial MSR, STMSR, respectively.

## 4. Conclusion

This paper showed that a spatio-temporal multi-scale retinex enhances dim images by effectively suppressing the noise. Our proposed method, STMSR, computes the time averaging of image sequences to suppress the noise in consideration of the moving vehicles in image frame. The experiments showed that the spatial procedure make the dark images distinguishable and effectively preserve the color information day and night while the temporal term reduces the noise and produces sharper and clearer reconstruction of the contents in each image frame. We showed through representative simulations that incorporating both terms in the modeling produces the output sequential images visually more pleasing than the original dim images.

All figures in this paper are color images. Since the present camera-ready paper is not in color, visit the following homepage for color enhanced images. (http://ispl.korea.ac.kr/~wjhwang/itc_csc2000.html).

## 4. Acknowledgement

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