An Improved Algorithm Inspired by Natural Biology for Image Enhancement Used in Space Station

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Abstract. In the space station, the uneven illumination of image brings significant challenges for image enhancement in vision system due to high dynamic range of light intensity and the light reflection of metal facilities. In order to solve this problem in monitoring, unattended operation and robot operation, Retinex algorithm was proposed to estimate the luminosity. However, the effectiveness of this method is highly dependent on the selected path and consumes huge computational cost. This paper proposes an algorithm inspired by the Archimedes spiral in natural environment to improve the processing time and enhance the images quality. First, the structure and mechanism of Human Visual System (HVS) are analyzed. Second, the original image is decomposed into the brightness and color layers based on the structural human eyes mechanism. Third, the brightness layer is processed by the improved Retinex algorithm to enhance the original image by merging it with the color layer. The proposed algorithm is validated with the experimental results.

1. Introduction

The vision system is the precondition of monitoring, unattended operation and robot operation in space cabin. The unevenness of lighting condition in the outer space poses great challenges in the vision system as regard to observation and recognition. The illumination intensity of solar directly radiating region is as high as 930000 Lux [1]. In the Spacelab, light levels are constant and low (approximately 10 to 100 lux) during the working day [2,3]. The dramatic illuminance makes it difficult to adapt to the vision system. Therefore, the way how human beings accommodate changing lightness provides an insight into this challenge research.

So far, a variety of traditional and classical techniques have been proposed to improve the image quality under complex illumination conditions. These techniques are usually divided into two categories: spatial processing and frequency domain processing [4–6]. Histogram equalization method often loses local information in image enhancement, which causes the unnatural look [7,8]. Beyond that, some other methods, such as the neighbourhood averaging, low-pass filtering, median filtering, and Bilateral filtering method, can also remove image noise, but the edges of which are always obscured [9,10]. Although the high-pass filtering and discrete space difference method is capable of enhancing the image edge, the image noise is also inevitably enhanced [11].

In this paper, a new method capable of producing excellent enhancing effect for high dynamic range image in the space station cabin is proposed. This method is based on Retinex theory and inspired by the Archimedes spiral in natural environment.
2. Structure and Mechanism of Human Eyes

2.1. Retinex Theory
In 1971, Edwin H. Land discovered a phenomenal in experiment that no matter how the spectrum of light changed, the observer is still able to figure out the true color of the object. This phenomenon is called the color constancy of the HVS. Inspired by the medical and psychology research, Land proposed the Retinex theory, which is the compound word of retina and cortex.

In the Retinex theory, the processed image is divided into a brightness image and a reflection image. By reducing or even eliminating the effect of the brightness image on the reflection image, the enhanced image is achieved. After the incident light from light source L casts on the object R, the reflection light of the object is reflected into the observer's eyes, which is what we see.

First, the image S is decomposed into the log domain. This process can be expressed as:

\[
\log[S(x, y)] = \log[R(x, y) \cdot L(x, y)] = \log[R(x, y)] + \log[L(x, y)]
\] (1)

Second, analyze the image S and estimate the incident light L. This is the focus of this enhancement algorithm.

Third, reduce the effect of the incident light L in the log domain.

Finally, convert the r(x,y) in the log domain to the reflection image R(x,y) in the real domain.

2.2. McCann's Retinex Algorithm
Although the McCann's Retinex algorithm makes the image more colorful, there are still some limitations.

- Halo: The cause of this phenomenon is that classical Retinex assumes the illumination changes smoothly, which result in halo effects in the high dynamic range image.
- Conflict between effectiveness and computational time: The advantage of MSR's Retinex is that the closer to the original pixel, the more pixels will be compared. However, in order to get a good dynamic compression and smooth image, excessive pixels are required to be iterated as well as iteration time, which slow down the processing speed and reduce the processing efficiency.
- Color distortion: MSR's Retinex processes the image independently on 3 different color channels in RGB. As a result, some colors are distorted after the 3 channels' images are composed.
- The lack of details in overexposure area: In overexposed highlighted images, the classical MSR's Retinex perceives the image structure by measuring the brightness level among adjacent pixels. For color images when been exposed to similar levels of brightness on either side of the edges, the edges can't be distinguished only by the brightness information.

3. Improved Retinex Enhancement Method Based on the Bionic Spiral
Aiming at the high dynamic range image with uneven illumination in space, an improved Retinex method based on the bionic spiral is proposed to solve the limitations mentioned above. This method is used to neutralize the extremely bright and dark areas at the same time in the image, make the illumination more uniform while show case the details, and improve the computation efficiency. The flowchart of the proposed method is depicted in Fig.1.

The image enhancement method is carried out in 3 steps:

Step 1: Isolate the brightness and color layer of the image. The color layer is reserved as image property, and the brightness layer is processed since it contains the illumination information.

Step 2: Estimate the illumination of the brightness layer based on bionic spiral and obtain the new brightness layer.

Step 3: The enhancement image is obtained by merging the new brightness layer with the color layer.
3.1. Separate Image Based on HSI Model

Based on the HVS, the HSI color space uses hue, saturation and intensity to describe colors. The image should be converted to HSI model first. This model is based on two important factors: one is the intensity component of the image is irrelevant to color information, the other one is the hue and saturation components are closely related to color that people perceives.

3.2. Illumination Estimation Based on the Bionic Spiral

To solve the conflict problem between the effectiveness of McCann Retinex and processing time, the extraction path of illumination estimation base on Archimedes spiral is proposed in this section. This method is able to capture the changes in illumination of the image with relatively fewer pixels.

Inspired by the spiral widely exists in nature, Archimedes spiral is adopted to extract the image illumination condition, as shown in Fig.2.

Fig.2 shows the extracting path of the improved Retinex algorithm. The path is:

\[
\begin{align*}
  x &= \text{fix}(e^{-in}\cdot\cos(t)+1)\cdot\frac{w}{2} \\
  y &= \text{fix}(e^{-in}\cdot\sin(t)+1)\cdot\frac{h}{2} \\
  t &\in [0,k\pi]
\end{align*}
\]  

where, fix is the integral function, \((x,y)\) is the pixel coordinate of extracting path, \(w\) and \(h\) are the pixel width and height of the image, \(n\) represents the density of the spiral and \(k\) is the circle number. The larger \(k\) is, the more pixels are involved, as a result, the enhanced image is smoother, but requires more processing time.

After the iteration completes, we can get:
\[ r_{i+1}(x, y) = \frac{r(x, y) + r'(x, y)}{2} \]  

where, \( r_i(x, y) \) is the result of the last iteration, \( r'_i(x, y) \) is the combination of \( r_i(x, y) \) and the luminance difference.

\[ r'_i(x, y) = \begin{cases} r_i(x, y) + \Delta f & \text{if } r_i(x, y) + \Delta f \leq \max \\ \max & \text{if } r_i(x, y) + \Delta f > \max \end{cases} \]

where \( \Delta f \) is the luminance difference of a point on the path, \( \max \) is the maximum number of pixels in \( S(x, y) \), \( r_{i+1}(x, y) \) is the intensity value of the new brightness layer after \( i \) times of iteration.

Finally, the calculated brightness layer and the color layer are recombined, and the HSI model is converted to the RGB model. Thus, the enhanced image is obtained.

4. Experimental Results and Analysis

The improved Retinex method is used to enhance the images of the target tools in uneven and obscure space illumination environment. Grey histogram-based images are presented to test the effectiveness of this method.

As shown in Fig.3, the image (a) is in low illumination, and the image (b) is enhanced by the improved Retinex method. Each image has two parts, the left one is a partial enlargement of the area in yellow dotted line on top left. It can be seen from the right parts of image (a) and (b), the contrast and brightness are both enhanced by the proposed method, and the color is also rich and natural.

![Original image](image1.png)  ![Enhanced image](image2.png)

(a) Original image  (b) Enhanced image

**Figure 3.** Image enhancement results in low illumination. (a) shows the original image and (b) shows the enhanced image

![Histograms of image in low illumination](histogram1.png)  ![Histograms of image in low illumination](histogram2.png)

(a)  (b)

**Figure 4.** Histograms of image in low illumination. (a) describes the histogram of original image; (b) describes the histogram of the enhanced image

Fig.4, (a) and (b) show the grey histograms of the original and enhanced image respectively. One can see from (a) that grey values of most pixels are below 90, which means the image is overall dark. However, the grey value distribution of pixels in (b) is uniform, which means the contrast of targets and background in the image is improved and facilitates the identification of the object.
As shown in Fig.5, the two images in column (a) are both taken in uneven illumination. One can see that shadows in the images on top are more concentrated than the images below. Images in column (b) are enhanced by the classical Retinex algorithm, while images in column (c) are enhanced by the improved Retinex algorithm. One can see from column (b) that the classic Retinex algorithm is capable of eliminating uneven illumination; however, it produces halos as well. In contrast, images in column (c) are enhanced by the improved Retinex algorithm, which eliminates both uneven illumination and avoid halo.

In Fig.6, (a) shows images of the tool under uneven illumination which the shadows are concentrated and dispersive respectively; (b) shows the enhanced images of (a) using the classic Retinex algorithm; (c) shows the enhanced images of (a) using the improved Retinex algorithm.

Images of Fig.6 are the grey histograms of images in Fig.5 respectively. From column (a) we can see that the gray values of pixels are mostly concentrated below 100, which means the original images is dark and the shaded area is large. Gray values of pixels in column (b) and (c) are similar which show that the values are mostly concentrated above 150. That means the enhanced images through the classic algorithm and the improved algorithm both have effects of increasing brightness the shadow, reducing the shaded area. However, we can see from column (b) that there are large number of pixels have brightness value of 255, which means the amount of halos is large in images of column (b). From
the contrast of grey histograms in column (b) and (c), we can conclude that the improved algorithm could eliminate halos and make the image clearer.

5. Conclusion
The high dynamic range of light intensity in the space station is an important issue in the computer vision. In this paper, an improved Retinex algorithm was presented based on the Archimedes spiral. This algorithm mainly solved the classical Retinex problem whose calculation is huge. The proposed algorithm of the improved Retinex has several advantages over the classical Retinex, such as processing time and the effects. However, it’s not so effective when the light is too low or the reflection is too strong. In the future, we tend to investigate instances of the space station and further optimize the algorithm for kinds of illumination.

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7. References
[1] Cheng L, Jiang Z, Li H, et al. A robust and efficient algorithm for tool recognition and localization for space station robot[J]. International Journal of Advanced Robotic Systems, 2014, 11(12): 193.
[2] Barratt, Michael R., and Sam Lee Pool, eds. Principles of clinical medicine for space flight. Springer Science & Business Media, 2008. P420.
[3] https://www.nasa.gov/536972main_Wings9.html
[4] Szytula A and Leciejewicz J 1989 Handbook on the Physics and Chemistry of Rare Earthsvol 12, ed K A Gschneidner Jr and L Erwin (Amsterdam: Elsevier) p 133
[5] Franceschini M A, Moesta K T, Fantini S, et al. Frequency-domain techniques enhance optical mammography: initial clinical results[J]. Proceedings of the National Academy of Sciences, 1997, 94(12): 6468-6473.
[6] Petrou M, Petrou C. Image processing: the fundamentals[M]. John Wiley & Sons, 2010.
[7] Kim Y T. Contrast enhancement using brightness preserving bi-histogram equalization[J]. IEEE transactions on Consumer Electronics, 1997, 43(1): 1-8.
[8] Kaur M, Kaur J, Kaur J. Survey of contrast enhancement techniques based on histogram equalization[J]. International Journal of Advanced Computer Science and Applications, 2011, 2(7): 137-141.
[9] Pal S K, King R. Image enhancement using smoothing with fuzzy sets[J]. IEEE TRANS. SYS., MAN, AND CYBER., 1981, 11(7): 494-500.
[10] Tomasi C, Manduchi R. Bilateral filtering for gray and color images[C]//Computer Vision, 1998. Sixth International Conference on. IEEE, 1998: 839-846.
[11] Makandar A, Halalli B. Image enhancement techniques using highpass and lowpass filters[J]. International Journal of Computer Applications, 2015, 109(14).