A robust image enhancement system for illumination variant image based on auto-tuning stochastic resonance

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Abstract

This paper is concerned with the image enhancement technique for the mixed illumination variant images by applying the stochastic resonance (SR) using the auto-tuning process. This process works properly in the dark and very low contrast images as well as bright images. The process was performed by adding randomly the noise and threshold in an image by manual tuning. The random addition of the noise and threshold lacks the effectiveness and is time consuming for manual tuning. In this paper, we developed a system that works on the images with the mixture of darkness and brightness. The SR is applied by combining the logical AND with the stochastic resonance. We also present the idea of auto-tuning of the summation iteration with random noise and threshold value by using the process related to the histogram calculation or mean median and mode. The combination of the logical AND with the SR and the idea of auto-tuning of SR reflects the novelty of our paper. We performed various experiments on various types of images under different conditions and confirmed the effectiveness of our image enhancement technique.

Keywords: Image enhancement, stochastic resonance, Logical AND, Auto-tuning, Histogram.

1. Introduction

The improvement of the visual perception of the images is known as image enhancement. Image enhancement technique is one of the most interesting areas of image processing because of its attractive objective. Image enhancement is needed for getting the better visualization of the images. The contrast and the brightness of the image are directly related to the visibility of the image.

We are applying the image enhancement technique on the illumination variant images either dark or bright or mixed illumination variants. Many images have a very low dynamic range of the intensity values due to the insufficient illumination and therefore need to be processed before they are made visible. In our previous work⁽¹⁾, we have applied the modified stochastic resonance (SR) process for image enhancement on illumination variant images which have to be tuned manually. The manual tuning is time consuming and less effective. SR is a phenomenon in which the performance of a low contrast image can be improved by the addition of noise and threshold in an image. The noise can be known as a nuisance, but the presence of noise in fact enhance the weak signal strength and enhances the property of the image. In our previous work, the image enhancement of dark and bright images was properly satisfied, but the images with mixed illumination variant were not satisfied.

In this paper, we are developing a novel system by combining the logical AND with our stochastic resonance. We have slightly modified the Collins type SR⁽²⁾ by keeping the threshold value at constant 0 with a random noise value, summing up the resultant image with only threshold applied image and then applying the logical AND for the final enhanced image. The combination of the logical AND along with our stochastic resonance technique reflects the novelty of our current research. Similarly, the idea of auto-tuning of the SR is presented by us for the very first time in this paper in case of image enhancement. The auto-tuning of noise and threshold, depending on the contrast of the image by calculating the mean, median and mode of the histogram for image processing is the very new step by us and it clearly reflects the novelty of our current research.

In order to give validity to our proposed algorithm, we perform our experiments on various types of mixed

illumination variant images taken under different dark or bright conditions. We calculate and draw a histogram for all the resultant images. We have used the face detection system⁽³⁾ for checking the effectivity of our proposed algorithm. The facial components present in an illumination variant images are not detected without performing any enhancement process which means the facial components present in a properly enhanced images can be detected after the image enhancement process. The images that were not satisfied by our previous works have been satisfied by our current method of image enhancement with proper histograms, visibility and proper detection of face without any error. We have performed our experiments on related types of selected images that are taken from different databases and some images downloaded from the internet

2. Related works

The current research is different from the state of the art of SR based techniques used in case of image enhancement. A large number of techniques⁽⁴⁾⁽⁵⁾ have focused on the enhancement of gray level images in the spatial domain which includes histogram equalization, gamma correction, high pass filtering, low pass filtering etc. R.K. Jha et al.⁽⁶⁾ proposed two SR based techniques for enhancement of low contrast images by using DSR. The experimented images are made darker by adjusting the contrast of the image but the summation iteration were performed manually instead of auto-tuning SR.

Peng et al.⁽⁷⁾, used non dynamic stochastic resonance for improving the system performance of adaptive histogram equalization by using SR in medical images. Ryu et al.⁽⁸⁾ proposed a method for enhancing feature extraction for low quality fingerprint images by adding noise to the original image. R.Chouhan et al.⁽⁹⁾ remarked a dynamic stochastic resonance technique in DWT domain for enhancing the images that are dark, grayscale and colored perception for the improvement of the input signal through the addition of external noise. The intrinsic noise of image for contrast adjustment is used in their technique which is capable of enhancing the image without spot artifacts, blocking and ringing. The images used in this process are the dark images that are made dark by the contrast adjustment, totally different from the original images taken in a dark environment.

A stochastic resonance based technique in Fourier and wavelet domain for the enhancement of unclear diagnostic ultrasound⁽¹⁰⁾ and MRI images⁽¹¹⁾ is reported by Rallabandi.

These methods can readily enhance the image by fusing a unique, constructive interaction of noise and signal, and enable improved diagnosis.

In this paper, we have used a new approach of applying SR along with the Logical AND for enhancing the image with the process of auto-tuning of the iteration number of the sum of the output image. Compared to the other related works, we are using the original illumination variant images that are taken under different illumination variant conditions instead of adjusting the contrast of the image for the experiment.

3. Stochastic resonance

3.1 Original SR technique

The idea of stochastic resonance (SR) was first presented by Benzi⁽¹²⁾ in 1981. Along with the development of the science, this phenomenon is being utilized in a wide field. It is mainly used in the field of signal processing. The concept of SR is defined as an addition of random white noise to the input image and then the threshold is applied to the image for extracting the hidden components of the image. The effect of the SR on the basis of the amount of noise added is shown in figure 1. The figure 1e represents the binarized image without any noise and the figure 1f represents the image after adding the noise on the binarized image. The effect of the SR results to the clear visibility of the image components.

The noise and the threshold have to be tuned manually in this type of SR which is not so adaptable. The experiment performed on a dark image by using this process is shown in Fig. 2 and the matrix showing the output image applying the face detector is shown in table 1⁽¹⁾.

Fig.1. Effect of original SR (a) No noise (b) Noise added image (c) Excess noise (d) Noisy image (e) Binarized image (f) SR added image

Fig.2. Example of images by basic SR with manual tuning;
 (a) Original dark image; (b) Noise = 1, threshold = 1;
 (c) Noise = 2, threshold=3; (d) Noise =4, threshold =4;

Table 1. Face detection results for Fig. 2(a).
 by manual tuning method of basic SR.

Threshold value	Noise Level					
	0	1	2	3	4	5
0	×	×	×	×	×	×
1	×	×	×	×	×	×
2	×	×	△	△	△	△
3	△	△	○	○	○	△
4	○	○	○	○	○	△
5	×	×	△	△	△	△

Fig.2 and Table 1 from our previous works (ref. 1)

3.2 SR without tuning: Type A SR

The “SR without tuning” or the “summing network” idea was developed by Collins et.al⁽²⁾. This idea was first applied as a summing network of the identical excitable units related to the signal interference devices by adding the random threshold and noise values. The figure 3 shows the algorithm for SR without tuning by Collins et.al.

As, we are doing our research on image processing, we will follow the PDM (pulse density modulation) in our process. The experimental results performed on dark images by using this process is shown in figure 4 tuned manually with noise value 3 and threshold value 3. In this case the face detection is not possible, or we can say the effect of the threshold is not visible in such cases.

We experimented the same image by simply modifying the Collins type SR keeping the threshold value at constant 0. The noise value is normalized from 0-255 range instead of 0-1 because the image is calculated in the pixel value instead of time. Then we sum up the white noise applied images for several times in a series. If we apply a threshold value larger than zero, the special features of the image degrades. This process works properly on the dark images but this process doesn't work properly on mixed illumination variant images as shown in figure 5.

Fig.3. Collins type SR: Type A SR (ref.1)

Fig. 4: Example of Collins type SR with noise value 3 and threshold value 3.

Fig.5. Example of type A SR on mixed illumination variant image

3.3 SR technique for image processing: Type B SR

This idea is developed from our “Type A” algorithm, which is also our previous works. In order to clear the problems and errors obtained from “Type A algorithm”, we developed a new idea of “SR technique for image processing: Type B” algorithm. The figure showing the proposed idea of “Type B” algorithm is shown in figure 6. In this process, the input image is passed to “SR technique for image processing: Type A” and in parallel, the threshold is applied in an input image. The two outputs obtained in parallel are then processed by using the “Logical AND” and the final output image is obtained. We checked the image shown in figure 5 by using “SR technique for image processing: Type B” and we were able to clear the errors and problems of our previous SR technique. The execution process of our “Type B” algorithm is shown in figure 7, which clearly reflects the effectiveness of “Type B” with the clear visibility of the image and no false positive faces.

Fig.6. SR technique for image processing: Type B SR

Fig.7. Example of type B SR

4. Proposed algorithm for auto-tuning SR: Type C SR

The noise plays a very important role in the field of SR. Noise can sometime enhance a signal as well as it can corrupt the signal. Noise can amplify a faint signal in some feedback nonlinear systems even though too much noise can swamp the signal. The noise and the threshold image have to be summed up in a series for several times in order to get the

In this paper, we are presenting the idea of auto-tuning for the iteration number of the summation times by using the histogram calculation process of calculating the mean, median and mode. The algorithm of our “Proposed auto-tuning SR: Type C” is shown in figure 8. In an input image, we apply “SR technique for image processing: Type A” and threshold in parallel. The SR applied images are then sent to the histogram calculation process, where we calculate the mean, median and mode of the image. If the mean is greater than $60 \cdot \alpha$, the median is greater than $50 \cdot \alpha$ and the mode is greater than $35 \cdot \alpha$, we will pass the SR applied image along with the threshold applied image to the logical AND for the final output image. This part reflects our “SR technique for image processing: Type B”. If the value of the mean, median and mode is not satisfied, the image is again passed to “SR technique for image processing: Type A” for image processing in a loop. The number of loops represent the summation times N . The “ α ” represents the safety factor of our system which is equal to 1 but in our system we have set it to 1.1 for unconditional errors.

The above mentioned value is satisfied in case of dark images, but in case of the bright image, the same value of mean, median and mode can be used, but the calculation

must be started by erasing the unused region of the histogram in the dark side. In our process, the range of the histogram is set from 1 to 254 instead of 0-255 because 0 and 255 shows the final black level and the final white level of the image which makes the calculation little complicated. The mean value, median value and mode are calculated as:

$$mean = \frac{\text{sum of the values}}{\text{total number of values}} ;$$

$$median = \frac{\text{total number of values}+1}{2} ;$$

$$mode = \text{highest repeated frequency} ;$$

The execution of this process is shown in figure 9. The figure 9a shows the final output image and the figure 9b shows the histogram of the final image along with the calculated mean, median and mode. The histogram of the output result clearly reflects the enhanced level of the image. In the histogram, the blue line represents the value of the mean region, green represents the median region and red represents the mode region. The value of the mean is 58, median is 43 and mode is 31 in this case. The figure 10 shows the graphical representation of the calculated mean, median and mode along with the iteration number of summation times of the image shown in figure 9. The noise value is 3

Fig.8. Proposed algorithm for auto-tuning SR: Type C SR

and the mean, median and mode value are changed until the final value is found as shown in graph. From the figure 9, the 10th times iteration satisfies the exact value range of the histogram.

(a) Output enhanced image using our proposed system

(b) Output histogram with mean, median and mode

Fig.9. An example of type C SR

Fig.10. Changes of the mean, median and mode by iteration number N of SR for example of fig. 8.

Fig.11. Evaluation of the proposed algorithm on mixed illumination variant images with the output values and result

5. Experimental results

5.1 Preparation for experiments

We performed some experiments on different illumination variant images under different illumination conditions. We used dark images, bright images and the mixed illumination variant images with the presence of both the dark and bright regions. To give validity to our current process, we have used the face detector⁽³⁾ to locate the facial region in the enhanced image. We have developed a C programming code by using the Visual studio 2010 and the Open CV library on PC (i7-3770, 3.40 GHz, 8GB main memory and Windows 8.1, 64 bit OS). The program takes the input image and gives the output image along with the histogram, iteration number of summation (N), the calculated mean, median and mode value, image size and the computational time of the given as shown in figure 11. After performing the experiment for several times and calculating the mean, median and mode value along with the quality of the enhanced image, we were able to fix the proper mean, median and mode value for our system.

We are performing our experiments on the original dark images taken by us, mixed illumination variant images downloaded from the internet by the author's permission and some selected images from the INRIA database⁽¹²⁾. It was quite difficult for us to collect the images for our current research as there is no specific database for the mixed illumination variant type images.

5.2 Evaluation of different image cases

We performed our experiments on different types of images under different illumination conditions on 5 cases as shown in figure 11. These are the conditions, which are very complicated for the image enhancement. The case 1 image is an original image taken in front of the illumination light, which is the image type with mixed illumination variant condition. The size of the image is 603 * 402 pixels. The noise level is set to 3 in this case. The iteration number of summation (N) is 10 along with the mean value 58, median 43 and mode 31. The computational time for this image case is 52ms. This is the unsatisfied condition for our previous works.

The case 2 is an original image taken in a dark corridor with a very small ray of light with no lightning effects. The size of this image is 400 * 300 pixels. The noise level is set to 3, the iteration number of summation (N) is 19 along with the mean value 56, median value 56 and mode value 45. Due

to the extreme darkness of the image, it took a long iteration to get the proper result. The computational time for this image is 96ms. The mean value and the median value for this case is same, so the median line and the mean line are piled up over each other due to which only two lines are visible properly.

The case 3 is also an original image taken outdoor in a dark environment with the mixed illumination variant. The size of this image is also 400 * 300 pixels. The noise level is set to 3. The iteration number of summation (N) is 8 along with the mean value 68, median value 45 and mode value 25. This case compared to case 2 consists of lights, due to which the image candidates are easy to extract and the image is enhanced in a few iterations than that of case 2 image. The computational time for this image is 48ms. The face is also detected properly. The output histogram clearly represents the calculated value of mean, median and mode in this case.

The case 4 image was downloaded from the PhotoJosh with the author's permission. This case is taken in front of the lightings, the image candidates on this image are properly visible as well. This image is also an example of the mixed illumination variant image, but under the bright environment. The size of this image is 821 * 526 pixels. The noise level is set to 3. The iteration number of summation (N) is 3 along with the mean value 140, median value 122 and mode value 102. This value is quite large according to our proposed range of our proposed system, but it does satisfies our conditions because, there is the unused dark region present with neither value in the output histogram. If the summation is performed after removing this unused region, then the value of mean, median and mode will satisfy our conditions. The computational time for this image is 32ms.

The case 5 image was also downloaded from the internet as it satisfies the image conditions for our experiment. This case can be known as the case under extreme brightness. For such cases, we need to invert the image at first before applying our proposed system. The image can be enhanced and the face can also be detected in such type of images, but the image of the histogram is totally different. In this case the image is enhanced but the histogram is not satisfied. The size of this image is 750 * 545 pixels. In this case, the noise level is set to 5, where the mean value is 105, median value is 99 and the mode value is 4. The mean value and the median value of this case can be accepted, but the mode value is very small due to the effect of the inversion of the image. The computational time for this image is 42ms on three times iteration (N).

5.3 Discussion

We proposed a new system for image enhancement on mixed illumination variant images using the auto-tuning SR for the first time. We performed our experiments on various types of illumination variant images and were able to get the effective result. This process automatically calculates the darkness or brightness of the image and results the mean, median and mode value of the image on the histogram. The iteration number of the summation series is less in case of brighter image when compared to the darker image. The effectivity of our image enhancement technique was validated by using the face detector, which is the best means of evaluation for the image enhancement. The images with extra brightness as of case 4 are the complicated tasks for the auto-tuning. Such images can be enhanced, but can't be auto-tuned. We need to implement a new idea for satisfying our proposed auto-tuning SR for the images similar to case 4.

The computational time of our system varies according to the size of the image and depends on the number of iteration (N) and the noise value. The fewer the iteration number the less is the time consumed. The fastest computational time of our proposed system is 32ms for the image of size 821 * 526 pixels as shown in case 3 of figure 11. The computational time for the one time iteration is near to 11ms for this image.

The computational time of our previous work on the case 3 image was 23.8ms, which was faster in compared to our current proposed method. The previous work was faster but the current work is effective and worthy with a difference of 10ms time. In compared to the manual tuning, auto-tuning is easy to implement.

6. Conclusions

We presented a robust image enhancement system for mixed illumination variant images by using the auto-tuning stochastic resonance technique. This work reflects the novelty of our research and clears the unsatisfied conditions of our previous works. The SR is performed automatically after detecting the contrast of the image. The system is fast and process the image within a second.

The images with mixed illumination variant condition were solved by using this system. This proposed image enhancement technique will help to increase the effectivity of the other image processing systems that depends on the image enhancement.

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