An auto-gain control algorithm for EMCCD based on dynamic gray-level

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ABSTRACT

According to the adjustability of the gain multiplier of Electron Multiplying CCD , an image gain adjustment method based on dynamic gray-level is proposed. Compared to a fixed value adjustment algorithm ， the automatic gain algorithm here is more adaptive,even in low-light conditions , it can achieve better gain values. Experimental results show that the automatic gain algorithm which combines mean values with the dynamic range of histograms meets the requirements. Whether it is during the day or at night , the brightness of image can quickly converge to the optimum range of gray histogram distribution, gray- level dynamic range is also accounted for more than 90% . Judging from the images obtained : the brightness is moderate, details are clear .

Keywords: EMCCD , Automatic Gain , dynamic gray-level ,low-light-level.

1. INTRODUCTION

With the continuous development of science and technology ,higher requirements for imaging system are in an urgent need in the field of industrial measurement, medical treatment ,and the military[1].After image feature extraction and segmentation ,the image recognition system identify the corresponding operation based on the recognition results and the quality of image is particularly important in such cases.If we have got the blurred pictures or the details are not clear enough, sometimes it may lead to erroneous results[2].No matter it is from industrial or military point of view,high-resolution imaging systems have a lot of practical needs.In order to achieve moderate and clear images automatically,an automatic gain algorithm combine the mean value with the gray level histograms dynamic range is proposed.

The automatic gain adjustment is to calculate the brightness value and the gain value of the current Electron Multiplying CCD(EMCCD) image ,adjust the gain value by comparison and feedback.It aims at adjusting the brightness of image automatically and upgrading image contrast.In this paper,by using the multiplication gain adjustable features of EMCCD, an improved algorithm is carried out.The algorithm first calculates the exposure time for the image to determine the current lighting situation and then predicts the desired gain of next image under the situation of mean brightness. Thus automatic gain adjustment of EMCCD image is achieved .

In this process, a dynamic calculation method based on gray level is raised as the exposure time calculated herein for the value , comparing to a fixed value calculating method this one has been more adaptable . The main procedure of the algorithm is to calculate the average brightness of the current image frame and analyze it.The current brightness is then performed to adjust the settings in order to further determine the corresponding exposure time.Then calculate the

Optoelectronic Imaging and Multimedia Technology III, edited by Qionghai Dai, Tsutomu Shimura,
Proc. of SPIE Vol. 9273, 92732J · © 2014 SPIE · CCC code: 0277-786X/14/$18
doi: 10.1117/12.2070216

multiplying gain based on a function of the exposure value and adjust it so that the next frame to achieve the appropriate brightness value.

2. THEORY OF AUTOMATIC GAIN ALGORITHM

AGC (Automatic Gain Control)schematic is shown in Figure 1 . Get an image from EMCCD , amplify the image signal through a variable gain amplifier,and then calculate the mean of the image.Exposure time is calculated and the feedback gain value is acquired by exposure function, and then adjusting the gain values of variable amplifier, thus the automatic adjustment of the gain value is realized .

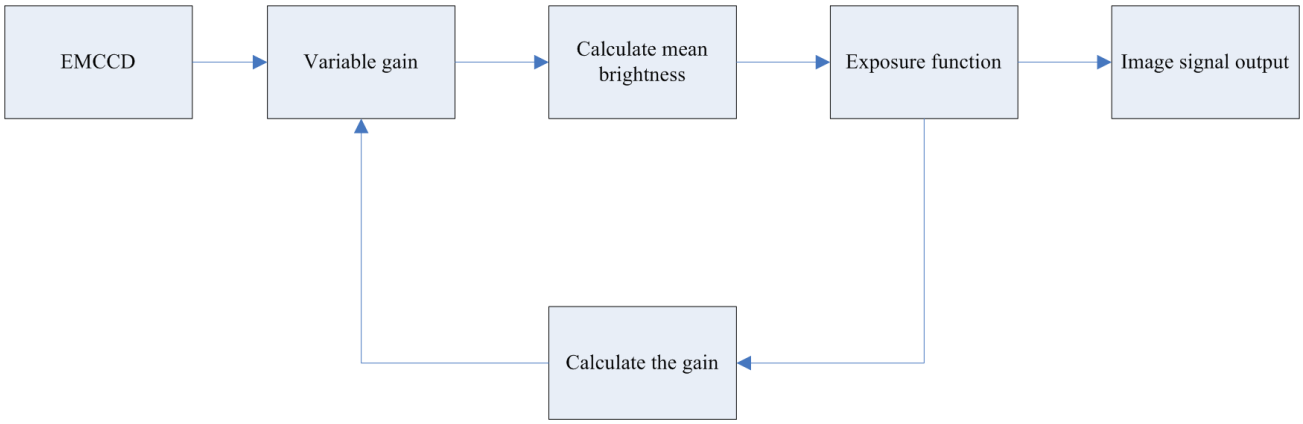


Figure 1.Schematic Automatic Gain

Seen from Figure 1 , in order to finish the subsequent calculation of the exposure and gain value , we need to calculate the current average brightness of the image . For an EMCCD image ,the brightness of image is influenced mainly by the ambient light intensity , the size of the camera aperture , exposure time, and the multiplication gain [3]. Several factors described above , the light intensity of the external environment by the natural light, which is not artificially constrained control ,so to achieve the adjustment of brightness, we need only three amounts to adjust the settings.

(1) Aperture

The size of aperture represents the amount of light entering the optical system.That is to say the amount of light is proportional to the size of aperture.The larger the aperture , the greater the amount of light per unit of time .The smaller the aperture , the smaller the amount of light per unit. There are two methods used for adjusting the aperture size , one is by manual adjustment , which is characterized by simple, but not fast and accurate.Another is to calculate the light intensity by collecting the current image signal and compare with a threshold value , and then turn the aperture through the MCU , such as motor control circuit , automatically adjust the aperture size .The advantage lies in the realization of the aperture automatically and precisely control the size , but not a high real-time . In the case of continuous image acquisition , this method can not achieve real-time and fast aperture adjustment .

(2) Exposure time

Exposure time is commonly known as the shutter , which parameter all the camera system has set . The exposure time and aperture size are complementary.For example,to increase the flux, either slow down the shutter speed to increase the exposure time ,or you can also add large aperture, so that more light can come .Through several experiments , a certain relationship between the quality of EMCCD image and exposure time was found, the relationship is when the aperture size and gain level are fixed , the longer the exposure time of the camera , the clearer the resulting image is and the pixel gray value is higher .However , the exposure time is one of the factors affect the low light level image quality , when the exposure time is too short , the entire image is on the low gradation and has poor image contrast , so the image is not clear , while the exposure time is too long , the overall image is too white, the entire image becomes saturation.

(3) Multiplication gain

Multiplication gain means to amplify the analog signal of EMCCD's output so the signal of image is amplified ,we can achieve the brightness of low light level image by multiplying the image signal amplification.Compared to ordinary CCD, EMCCD has a solid state Electron Multiplying (EM) register at the end of the normal serial register[4-6],this register allows weak signals to be multiplied ,so EMCCD can work under low light level ,such as night vision imaging under night environment. The gain of EMCCD has great effect on the quality of the low light level image.The content and characteristics of EMCCD images also show differences when the gains are at different levels .When the gain is low,the image display the whole range of EMCCD scene , but the edge contour of the image is blur and image contrast is low,while the gain is at high level , the edge details of the image are significant with brightness increased. But for the enhancement of gain, the noise is also amplified so that the region of image generating saturated .This means when at a high gain level, a partial region of the image becomes blurred white. Controlling gain level automatically plays an important role and has significance of the quality of EMCCD imaging .Details about the adjustment algorithm for improved automatic gain will be discussed.

3. REALIZATION OF AUTOMATIC GAIN ALGORITHM

3.1 Judgments of Automatic exposure

Currently,all system of cameras can set the exposure automatically,this means the imaging system is to replace the manual calculation based on certain rules.Capture the target object by automatic exposure camera, so that the image will have a luminance size. The main processes of automatic exposure generally include light intensity detection, scene judgment and exposure compensation these three steps[7]. Automatic exposure are used in two ways: one is based on the form of electronics , and the other is based on optical form.The method of Electronics is to measure the illumination by way of the output signal of the imaging device . And the optical mode need to use a separate image sensor to detect the intensity of light , and the information of image obtained by the imaging sensor .The content information and the luminance information of images are processed separately by the imaging system. While the measurement speed of optical is faster, we need to add an external metering sensor to detect the brightness of the current environment , so the structure is more complicated. However, the speed of electronically is not quicker , the output signal for measuring the brightness of the environment of the current signal comes directly from the imaging device , so we need no additional photometry sensor , and therefore its structure is simple and easier to achieve .

According to existing literature studies [8-9] : In an imaging system, and an ambient light brightness of the image, we can learn the incident light intensity , exposure time ,aperture size and gain are as a function of the relationship , people called this exposure function ,namely:

$$B = f\left(E, F, T, G\right) \tag{1}$$

Where B is the brightness of image , E is the incident light intensity, F refers to aperture size, T as exposure time ; G as multiplication gain ; f as exposure function..

As used here is the method of electronics , the general auto exposure by the object is to make the brightness of the image in a ' 18% halftone ' brightness , so before the automatic exposure outset we need to obtain the luminance information about the current image. By calculating the brightness information of the entire image, we know the distribution of the image gray value , then after a certain judgment ,it will be able to know the current lighting condition

of the camera . After completing the brightness analysis , the imaging systems will make appropriate adjustments to exposure parameters through a certain algorithm , and make the brightness of next frame image ultimately tends to achieve the desired brightness. To adjust the exposure parameters we generally change the aperture size, exposure time and camera gain.

(1) Intermediate brightness according to a fixed value

The commonly used algorithms generally define the ideal brightness into the middle of the overall of the image's brightness , that is to set a fixed value[10]. The method fits well under normal lighting conditions , but in some special lighting conditions , such as when the subject is i backlight or exposed to strong positive light irradiation , then the scene of the brightest and darkest areas contrast big differences.And if it continues to adopt an intermediate brightness fixed value method will result problems that the target image will be overexposed or inadequate in some regions and the main details may be lost in such conditions.In addition to the low light level image,most of the gradation values are concentrated in the lower gray level .And when the gain is increased , the gray gradation begins to shift to higher . To set a simple fixed value will result in underexposed or overexposed. Therefore, according to the characteristics of low light level image and to improve the conventional automatic exposure algorithm based on the fixed value of intermediate gradation , a new method is proposed .The intermediate luminance value changes while the set of imaging brightness changes, so the luminance value can dynamically change .

(2) Dynamic values

In this paper, an improved algorithm is proposed .This algorithm set values of middle brightness into a dynamic change rather than a fixed one , it varies with the light conditions . Generally the first step of the algorithm is to acquire an image and calculate the brightness , then analyze the brightness of the image and judge the current light conditions of the image . Here are the appropriate criterion , when the light intensity is within the range of ordinary light,it belongs to conventional light conditions ,while the light intensity is less than or greater than a setted threshold , it means backlight conditions or positive light irradiation .After the judgment of lighting conditions , comes the appropriate treatment . If the lighting conditions are common lighting conditions , follow the "middle brightness " and set a fixed value for computing the correlation . However ,if we meet the special light conditions , press a special algorithm steps and exposure compensation. There are two ways to determine whether the current shooting environment is a special case of illumination : one is to calculate and judge based on the histogram of the image feature parameter , the other is to divide image area according to each region between the features of the image and calculates the brightness contrast to make judgments.

The EMCCD imaging system is operating in continuous mode,and the approach here is to calculate the exposure time of a next frame image from the luminance information of the image before.Then we have the multiplication gain based on exposure time corresponding function.Automatic exposure mode here is based on the realization of electronics and it is using the above dynamic value to judge and execute ,then it applies characteristic parameters of the imaging histogram analysis to determine whether the current situation is special lighting conditions or not.

3.2 Exposure time calculation

Specific detailed steps described as follows :the first step is to set a gray optimal range, calculate the mean gray value of images and dynamic distribution histogram of the gray level , then determine the lighting conditions :

(1) Calculate the average brightness of the first frame image , if the brightness is not in the best mean gray value range , then calculate the corresponding exposure time so that the current average will be at best gray image brightness range. If

the exposure time can not be changed by the frame speed constraints , then calculate the multiplication gain using the compensated image brightness .

(2) When the luminance values of the mean gray level falls within the optimal range, the next step will to determine the current condition of the image's illumination , a specific method to distinguish a general illumination conditions or special illumination conditions is calculating the distribution of the histogram luminance of images. When it is under the general lighting conditions , calculate the dynamic distribution of the gray level histogram ,and determine whether the gray level distribution is more than 90% ,if it not reached, adjust multiplication gain until the dynamic distribution of the histogram is over 90% , then calculate the required exposure time and multiplication gain of the next image according to the current image gray value , exposure time and gain multiplication.

3.3 Automatic Gain calculation

After the exposure time was calculated, gain value can be derived from a function (2) equation automatically ,then EMCCD automatic gain adjustment was achieved. Currently we use mean image, gray level histogram of the image and value of the dynamic range and other parameters for AGC . Among the algorithms used at present,most of them are using the the mean as a control volume .However, it is easy to produce a large deviation with single control amount, and because EMCCD capture images in real time ,the means of images is not the same at different scene. When the gains of EMCCD change , the mean value of brightness of the image may change , so only use mean as EMCCD gain control for gain adjustment may produce unexpected deviations.The histogram of the image contains a variety of the features . Therefore, this article adopt mean brightness and gray-level histogram as automatic gain control to adjust the volume . For a scene with rich details and proper gain, the distribution of image histogram has a wide range. However the gain value is too small or too large, the distribution of the histogram of the gray level will be small .

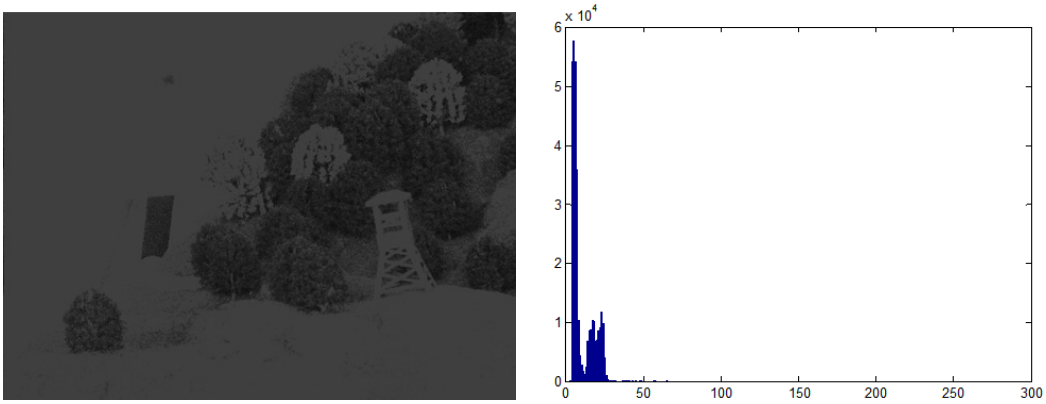


Figure 2. histogram distribution of EMCCD image

As seen in Figure 2 ,the calculated mean brightness is large , but from the histogram gradation distribution ,we can see the intensity distribution in the image area are smaller ,therefore we can not judge the gain of image is too small or too large only depending on the brightness of the image , in this paper,the automatic gain control to adjust the amount is to calculate the mean image brightness combined with the dynamic range of histogram .

Through the above analysis , in the case of continuous shooting , we can calculate the mean brightness of the image and the corresponding determination to get the exposure time of each image , the following values need to be calculated in accordance with the corresponding gain exposure functions[11-12]. From the above we know that exposure function is:

$$B = k \times E \times G \times T / F^2 \quad (2)$$

Where

k the coefficient for the imaging system ;

E incident light intensity ;

G multiplication gain system ;

T exposure time ;

F aperture size.

In the current exposure time T and the multiplication gain G, the brightness of the image obtained as B . When the brightness image does not reach the ideal brightness image B_0 of next frame , then need to calculate the brightness using the brightness of the image needed to achieve the desired exposure time T_0 and gain multiplier G_0 .

$$B_0 = k \times E \times G_0 \times T_0 / F^2 \quad (3)$$

the ratio of Formula (2) and the formula (3) , to give the formula (4) :

$$\frac{B_0}{B} = \frac{T_0 \cdot G_0}{T \cdot G} \quad (4)$$

Obtained from the above equation , based on the current exposure time, multiplication gain , image brightness,also the ideal image brightness B_0 and exposure time T_0 set in advance , we can calculate the required gain of next frame . That follows the formula (5) :

$$G_0 = \frac{T \cdot B_0}{T_0 \cdot B} \cdot G \quad (5)$$

In this process , the calculation of the current image brightness, combined with the analysis of the histogram of the current image of the gray level distribution .thus determine the current value is too large or too small , then calculate a gain value corresponding to the above formula and adjust accordingly . Figure 3 is a general flowchart of dynamic gradation automatic gain algorithm.

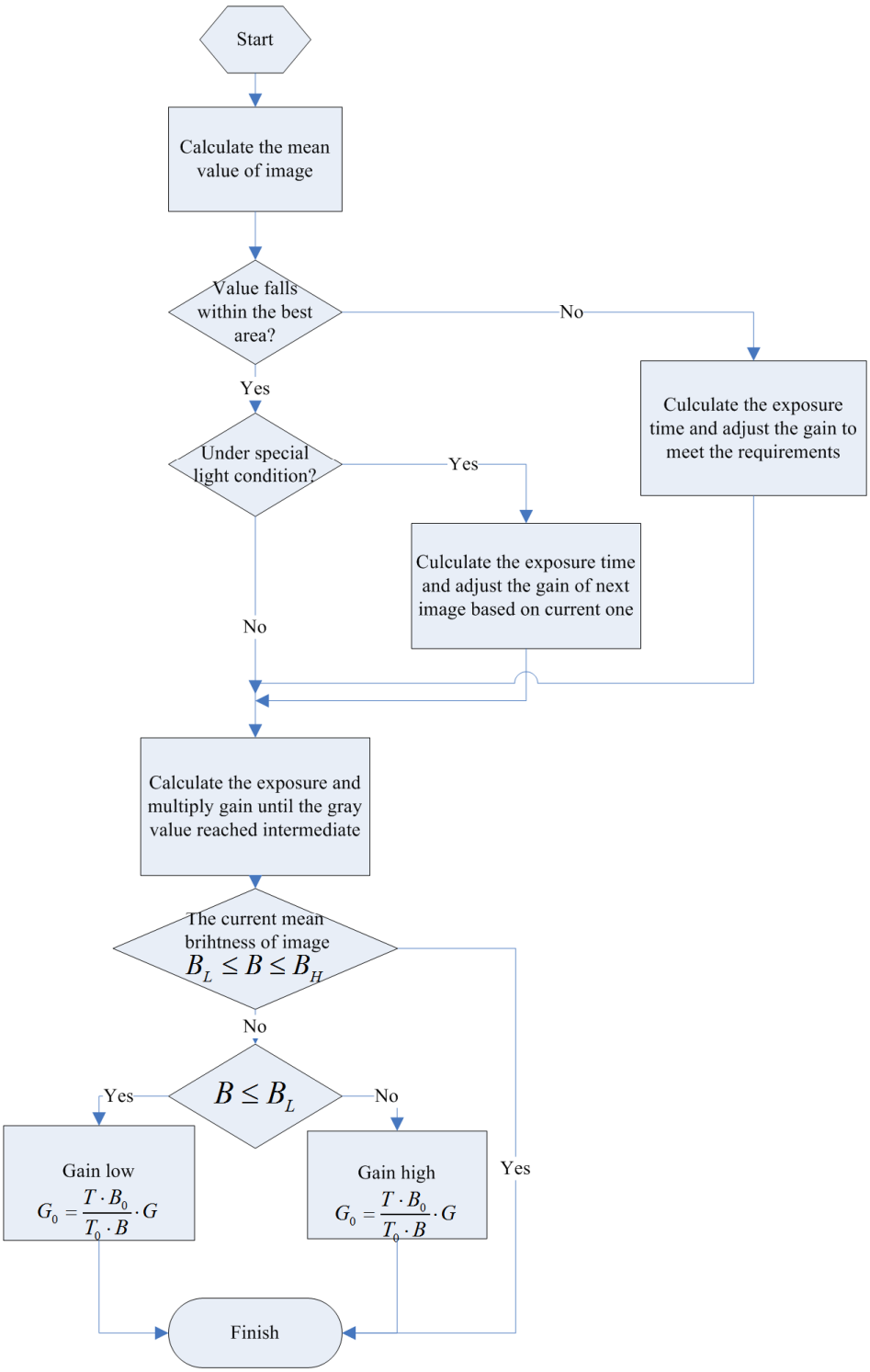


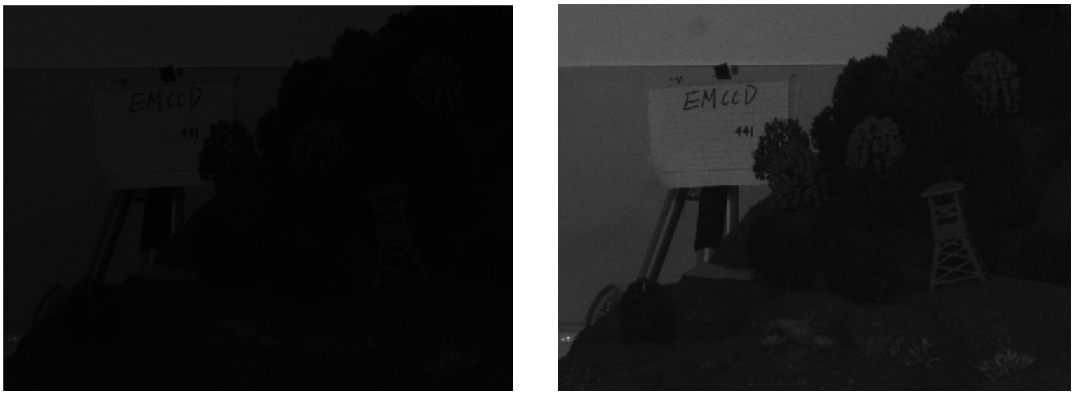
Figure 3.flowchart of dynamic gradation automatic gain algorithm

A detailed flowchart algorithm of Automatic gain in this paper is as shown above. First set the right aperture size under good lighting conditions , and set the appropriate exposure time and multiplication gain , this time the exposure time and gain the are initial value . Then in the initial shooting situations to get the first image , calculate the mean of the first image brightness and determine the brightness , the results of the analysis by calculating the mean brightness falls within the ideal range of best area,If it falls outside the ideal area , then judged by comparing the threshold set from the relevant light conditions before , we can determine that the lighting situation is underexposed or overexposed at this time, and then the corresponding algorithm based on exposure time and gain multiplier adjusted accordingly , so that the mean brightness will meet the requirements;If the area falls within the ideal region, we should judge whether the illumination light is a special case, if so ,then calculate the exposure time and gain multiplication according to the algorithms under particular lighting conditions and obtain the relevant adjustment amount so that the image gray value is reached the ideal halftone region ; Finally,the multiplication gain and exposure time of the next image needs to be calculated based on the current exposure time and multiplication gain calculate by the and exposure time .

The gain of amplifier can be automatically performed with the intensity of the image signal by the automatic gain control . To avoid the image brightness brighter or dimmer,the image is moderate bright . The exposure intensity mainly reflected by the brightness of image, when the camera has a fixed aperture and gain signal , the exposure intensity is proportional to the exposure time , i.e., the longer the exposure time , the greater the intensity and the image is more bright. For the exposure intensity can be adjusted by changing the exposure time and gain multiplier . Most cameras can set the frame rate when taking pictures , in case frame rate is higher or are restrictions, such as requiring imaging system when the camera 's frame rate is not less than 20 per second, this time exposure time can not exceed 1/20s.Some of the higher-speed cameras have higher requirements about frame rate , the exposure time of the system at this time will be shorter, so we need to increase the brightness of the image only by increasing the gain of the image signal .

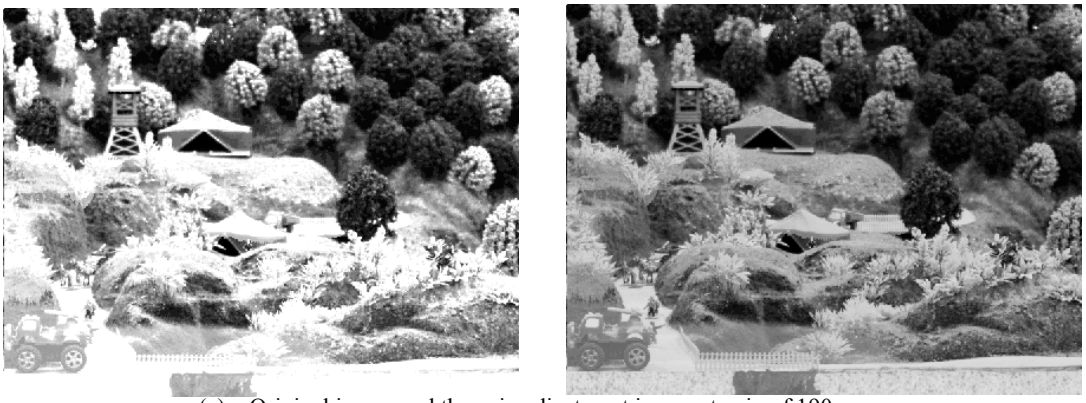
4. ANALYSIS OF EXPERIMENTAL RESULTS

In accordance with the flow chart , the actual simulation algorithm is carried out .we collect the pieces of Low Light Level images and histogram distribution are analyzed , the experimental results show that the proposed improved automatic gain algorithm can effectively improve the brightness and contrast of the image. Specific effects after adjustment as listed below,we use images under three different gain levels through automatic gain adjustment, the contrast images of EMCCD are shown .



(a) Original image and the gain adjustment image at gain of 50

(b) Original image and the gain adjustment image at gain of 100



(c) Original image and the gain adjustment image at gain of 190

Figure 4. Original image and the gain adjustment image at different gains

5 .CONCLUSION

Through several experiments to verify the all above, we can see in this paper that the method of the image gain adjustment based on dynamic gray-scale is overcome not only the inconvenience but also the inaccuracy of the manual settings. After the calculation of mean brightness of the image ,this algorithm determines the current brightness, and then adjusts the gain value .Compared to a fixed value adjustment algorithm ,the value of the exposure time we received is more adaptable,even in some special lighting conditions (such as under backlight conditions),it can achieve better gain

value by automatic adjustment . The brightness and contrast of image are improved and the local details of the image enhanced.

REFERENCE

[1]W. C. Kao, C. C. Hsu, C. C. Kao, and S. H. Chen,"Adaptive exposure control and real-time image fusion for surveillance systems," Proc. of IEEE Int. Symposium on Circuits and Systems, Kos, Greece, vol. 1-11, pp. 935-938(2006).

[2]De Young Mark,"The use of multiplication gain in L3 Vision TM electron multiplying CCD sensor."Al A-Low-Light Technical,(2003).

[3]Rong Zhengzhou,"Design of digital camera processor and study of system integration . "Shanghai: Fudan University,(2004).

[4]DENVIR D J, CONROY E,"Electron Multiplying CCD Technology: The new ICCD", Proc. SPIE, 4796: 164~174(2003).

[5]JERRAM P, POOL P, BELL R, et al.. "The LLLCCD: Low Light Imaging without the need for an intensifier." Proc. SPIE,4306: 178~186(2001).

[6]DENVIR D J, COATES C G,"Electron Multiplying CCD Technology: Application to Ultrasensitive Detection of Biomolecules. "Proc. SPIE, 4626: 502~512(2002).

[7]Nitin Sampat et al,"System implications of implementing auto-exposure on consumer digital cameras. "SPIE Conference on Sensors, Cameras,and Applications for Digital Photography, San Jose:p100-107(1999).

[8]T.Takagi,"Automatic exposure device and Photometry device in a camera,"US Patent: 4984006(1997).

[9]N.SamPat,Shyam Venkataraman,Thomas Yeh and Robert Kremens,"System Implications of implementing auto-exposure on consumer digital cameras",Proceedings of the SPIE Conference on Sensors,Cameras,and Applications for Digital Photography.Vol.3650.l:pp100-107(1999).

[10] J. S. Lee, Y. Y. Jung, B. S. Kim, and S. J. Ko, "An advanced video camera system with robust AF, AE, and AWB control," IEEE Trans. Consumer. Electron., vol. 47, pp694-699(2001).

[11]Stanislav Vitek, Jiri Hozman,"Image quality influenced by selected image sensor parameters."Proceedings of SPIE on Photonics, Devices, and Systems II:p14-19(2003).

[12]J. Y. Liang, Y. J. Qin, and Z. L. Hong, "An autoexposure algorithm for detecting high contrast lighting conditions," Proc. of the 7th Int. Conf. on ASIC, Guilin,Peoples R. China, vols. 1 and 2, pp725-728,(2007).