Adaptive Contrast Enhancement Using Local Region Stretching

S. Srinivasan[1], N. Balram[2]
[1]Marvell India Pvt. Ltd.,Bangalore, Karnataka 560017, India
[2]Marvell Semiconductor Inc.,Santa Clara, CA 95054, USA
ssujith@marvell.com, nbalram@marvell.com

Abstract: *This paper describes a real time contrast enhancement technique for digital video applications. This method called ACE is based on a modified histogram equalization procedure that adapts to the input video statistics. The method decides whether to increase dynamic range or to light up dark regions of the image. As a result, for dark images, details in dark areas are enhanced without affecting mid and bright pixels. For images with average brightness, the dynamic range of the scene is increased. Thus it is adaptive and provides a localized contrast enhancement effect which is not possible with traditional contrast stretching based approaches. Unlike other histogram equalization based approaches, the technique described automatically tones down its effects on pictures that are prone to contouring and other artifacts. The implementation offers a high degree of flexibility that is needed for consumer electronics applications such as provision of various degrees of enhancement and exclusion of letter box regions.*

Keywords: Digital video processing; adaptive contrast enhancement; ACE; histogram equalization.

Introduction

Contrast enhancement is one of the important video post processing tasks required to improve the picture quality on flat screen displays and other consumer electronics applications. Usually the video processing is done in digital domain using an ASIC or microcontroller with optional software support. In such a scenario, any video processing algorithm must run in real time and use minimum hardware complexity.

Digital video is usually stored and transmitted in the YCbCr format, quantized to eight bits resolution. One advantage of the YCbCr color space is that the luminance (brightness) and chrominance (color) information are separated. The Y component represents luminance while Cb and Cr represent color. Hence contrast enhancement algorithms for video applications usually process Y and bypass Cb and Cr.

Summary of Existing Techniques

Existing contrast enhancement techniques for digital video applications fall under two broad categories – contrast shaping based and histogram equalization based methods. Although the underlying methods of these approaches are derived from image processing, they cannot be directly applied to digital video. This may lead to over-enhancement and other artifacts such as flickering, contouring etc. Thus traditional image processing techniques must be adapted for video applications and especially so for the consumer electronics industry.

Contrast shaping methods work by calculating an input-output luminance curve defined at every luminance level. The shape of the curve must depend on the statistics of the video frame being processed. For example, dark images would have a dark stretch curve applied to them. Examples of this type of approach can be found in [1], [2] and [3]. In a video system which has a gamma look up table (LUT), the LUT has been used to implement the contrast look up function. Although contrast shaping methods are the most popular methods used in the consumer electronics industry, they cannot provide a localized contrast enhancement which is desirable. For example, when a dark stretch is performed, bright pixels become brighter. However a better way to enhance darker images is to stretch and enhance the dark regions, while leaving brighter pixels untouched.

Histogram equalization (HE) is a method to obtain a unique input to output contrast transfer function based upon on the histogram of the input image. HE results in a contrast transfer curve that stretches the peaks of the histogram (where more information is present) and compresses the troughs of the histogram (where less information is present). Thus it is a special case of the contrast shaping technique. As a stand alone technique, HE has been used extensively in medical imaging, satellite imagery and other applications where the emphasis is on pattern recognition and bringing out of hidden details. HE by itself results in too much enhancement and artifacts like contouring which is unacceptable in consumer electronics. Many techniques have been proposed to deal with these problems. In [4], the histogram is divided into two parts based on the input mean, and each part is equalized separately. This preserves the mean of the image to a certain extent. In [5], each peak of the histogram is equalized separately. An adaptation of HE, termed as Contrast Limited Adaptive HE (CLAHE) [6] divides the input image into a number of equal sized blocks and then performs contrast limited HE on each block. Contrast limiting is done by clipping the histogram before HE. This tends to tone down the over enhancement effect of HE and gives a more localized enhancement. However it is much more computationally intensive than HE. If the blocks are non-overlapping, an interpolation scheme is needed to prevent blocky artifacts in the output picture. Using overlapping blocks can solve this problem (every pixel is replaced by the HE output using a neighborhood) but is more computationally intensive than using non-overlapping blocks. CLAHE also requires a field store.

Histogram Equalization (HE)

HE [8] attempts to improve the contrast of an input image by stretching the peaks of the histogram and compressing the troughs. Considering a digital image which has N pixels distributed in M discrete luminance levels (assuming luminance processing only). Let n_k be the number of pixels with luminance y_k , where k Є [0, M-1]. Then the probability density function (PDF) of the image is

$$f_k(y) = \frac{n_k}{N} \quad (1)$$

The histogram of the image is a scaled representation of the PDF. The cumulative density function (CDF) is defined as follows:

$$F_k(y) = \sum_{i=0}^{i=k} f_k(y) \quad (2)$$

The CDF is a non-decreasing function that goes from 0 to 1. The input-output relationship of HE is then:

$$y_{out} = y_{\min} + (y_{\max} - y_{\min})F_k(y_{in}) \quad (3)$$

where y_{min} and y_{max} are the minimum and maximum permissible luminance values. For video systems, these values are usually 16 and 235.

By itself, HE is typically not used for contrast enhancement since it over enhances the image and produces undesirable artifacts such as contouring, noise amplification and gray level crushing. This can be seen in Figure 1. The main reason for this is that HE stretches the peaks of the histogram too much and consequently neighboring gray levels are pulled apart (much more than plain contrast stretching) and hence look discontinuous.

Proposed Algorithm

From Figure 1 it is obvious that HE cannot be used directly for consumer video. The proposed method presented here [7] uses HE in a controlled and localized manner to stretch the details in dark images while improving overall contrast in brighter ones. It is referred to as Adaptive Contrast Enhancement (ACE) because of the locally adaptive effect that is produced in each frame.

The proposed algorithm begins by dividing the histogram of the luminance levels into three regions – dark, mid and bright. These regions were of equal size. Each of these three regions is then processed independently using HE. The effect of HE is then toned down depending on the shape of the histogram of each region. This independent processing has two main advantages. Firstly, it brings out the details in dark images while keeping brighter pixels untouched. Dark images are much more common than bright in consumer video and hence improving their contrast is the most important application. Secondly it has the ability to create a subtle yet desirable enhancement without modifying the whole image too much. Figure 2 shows the regions of the luminance range that are used in the proposed method.

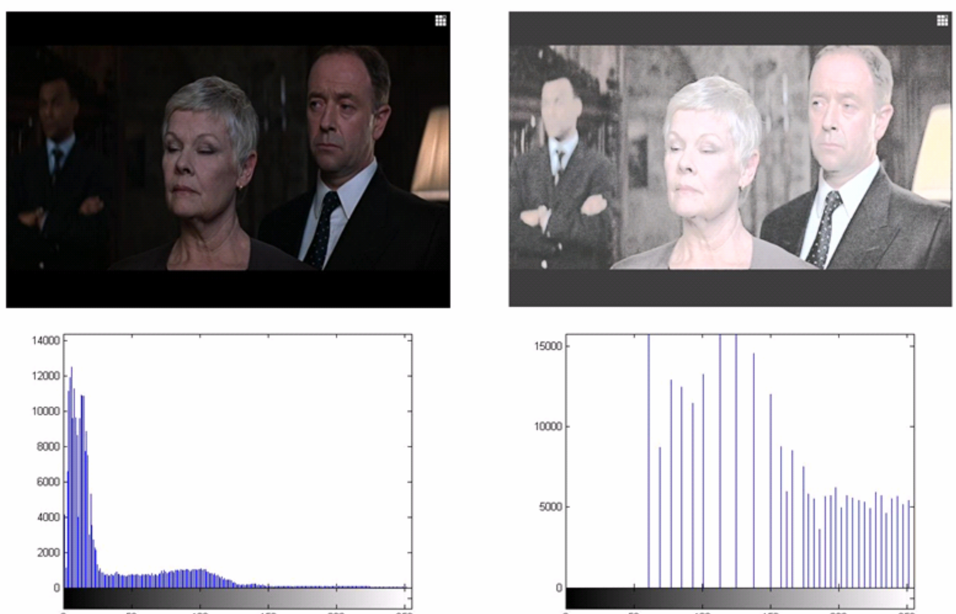

Figure 1. Effect of Histogram Equalization. The image on the top left has a histogram with a large peak. The histogram is shown below it. The image on the right is the output of HE. Note how the peak has been stretched.

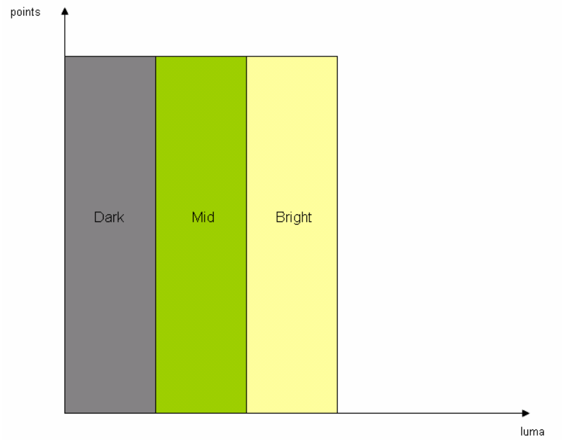

Figure 2. Luminance divisions used in the proposed method.

Once HE has been performed independently for the three regions, the final output is obtained by taking a weighted average of the input with the HE output. This weighting factor is independently calculated and controlled for the three regions. There are two reasons for performing this weighted average. Firstly, it can be used to control the level of enhancement and is well suited to program modes of operation such as low, medium and high settings. This is desirable for consumer electronics. Secondly, and more importantly, it can be used to adjust the level of enhancement differently for the three regions.

The weighting factor for each region of the histogram is calculated from the pseudo-variance of each region. First the mean luminance value of each region is found. Then the mean value is used to calculate the pseudo-variance using

$$\sigma_i = \frac{1}{N}\sum_j n_j(|y_j - m_i|) \quad (4)$$

where m is the mean luminance value, y_j indexes the luminance value, n_j is the number of points at luminance level y_j, N is the total number of points in the region and σ_i is the pseudo-variance of the region. The summation in (4) is carried out over all pixels belonging to one region and subscript i Є [1, 3] refers to the region being processed. The term pseudo-variance is used since the summation in (4) uses the absolute difference instead of square differences. This reduces the hardware complexity.

The variance is an indicator of the shape of the histogram. Its value is least when the histogram is concentrated around a few luminance levels and maximum when the histogram is such that half the pixels are close to the minimum and maximum luminance values of the region. In the proposed method, the weighting factor on HE output is related to the variance as shown in Figure 3. The weighting factor is low when the variance value is close to either minimum and maximum and high in between. The reasoning behind this relationship is this: when the variance is very low, the histogram is concentrated around a mean luminance value. HE would then stretch the histogram causing artifacts as seen in Figure 1. Hence a low weighting towards HE output is desirable for this case. A similar reasoning can be applied to the maximum variance case. For values of variance in between, a higher weighting to HE output is necessary. The transition should be smooth and continuous as in Figure 3.

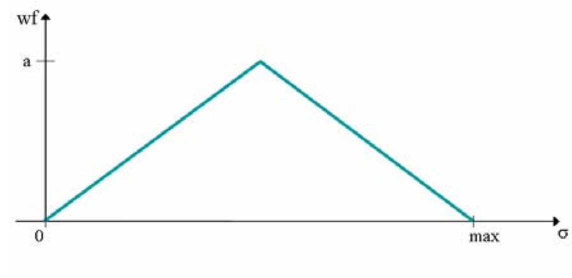

Figure 3. Relationship between weighting factor and variance of the histogram in the proposed method.

The peak of the triangle in Figure 3 (shown as *a*) can also be programmed differently for the three regions. This is required so that a higher emphasis on HE output can be used in the dark region and progressively less HE output will be used for the mid and bright regions. This was found to be the best setting for digital video, as it stretches the dark regions more while affecting the other regions less. As explained previously, dark images are more common and bringing out the details in these dark regions is required more often. The method proposed here is well suited for that while at the same time, the dynamic contrast for images with more information in the mid or bright regions is increased.

Results

Figure 4(b) shows the effect of the proposed method on an image with average brightness. The image 4(a) is the original while 4(b) was enhanced using our algorithm. For this image the dynamic range of the picture increases. Since most of the information is in the mid luminance range, making dark pixels darker increases the contrast and provides a better visual experience. In another example, Figure 4(d) shows the effect of the algorithm on a dark image. In this case most of the information lies in the dark region and therefore making dark pixels darker would not help. . It can be seen from the enhanced image, that the dark pixels are made lighter in this case so that details are enhanced. At the same time the people's faces and other bright pixels are not modified and so the algorithm gives a localized contrast enhancement effect. In many video applications, the pictures may have a letterbox which is usually dark. If the letterbox regions are used for HE processing, they will skew the histogram and the final output will be sub-optimal. The letterbox region will be processed by HE and may become lighter, which is not desirable. This problem is solved by doing automatic letterbox and pillarbox identification at the front-end of the ACE block and extracting only the active window of the frame for processing by the algorithm. The proposed method was

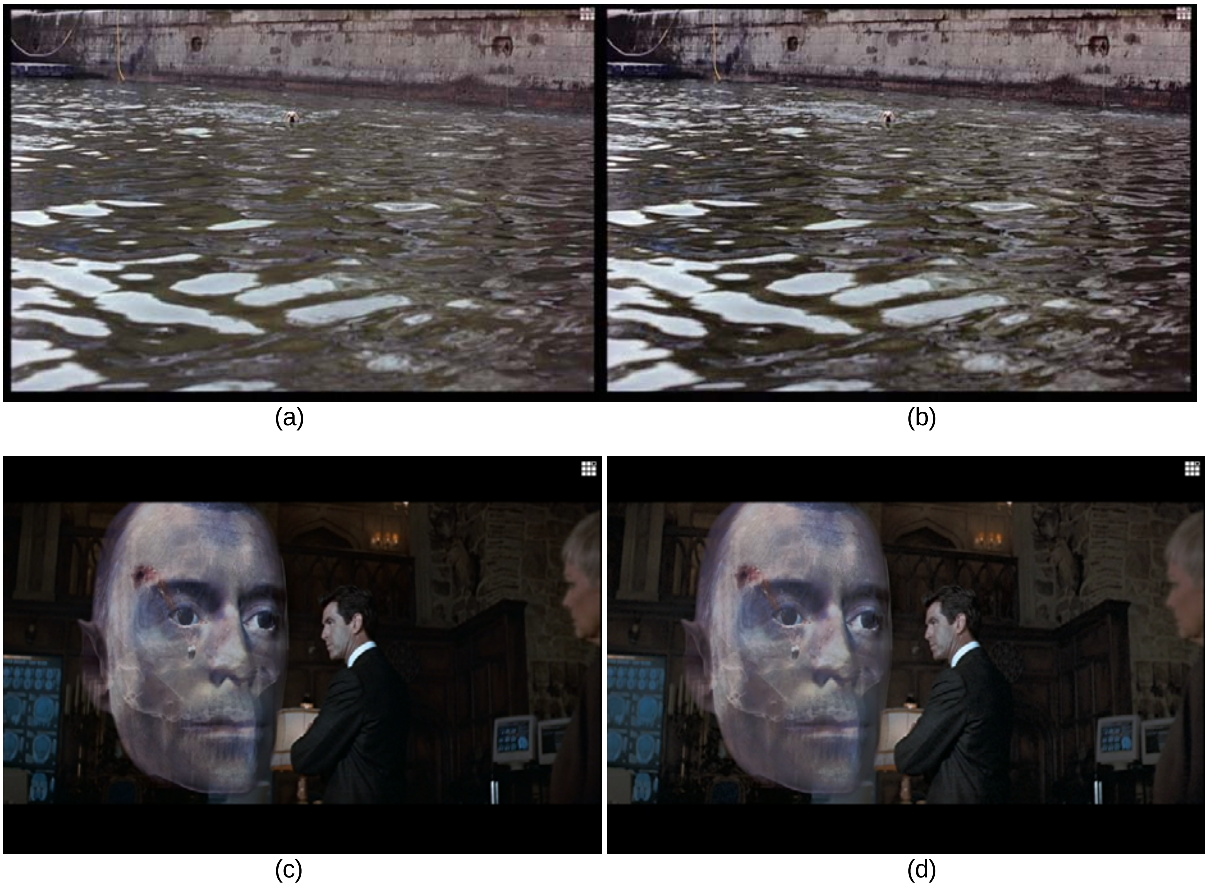

Figure 4. Results of contrast enhancement. The original images are on the left and enhanced images are on the right. Note how the dynamic range is improved in (b) while the darker regions are made brighter in (d).

implemented on an ASIC and tested with real video. For processing video frame storage was avoided by using the statistics collected from the previous frame to process the subsequent frame.

Conclusions

In summary, a method to enhance the contrast of digital video signals using a modified histogram equalization technique was proposed. The algorithm called ACE calculates the amount of enhancement needed depending on the shape of the histogram. The algorithm is able to increase the contrast range for images with average brightness while lighting up darker images. As a result it produces a localized adaptive effect. It is free from the artifacts usually associated with histogram equalization and is well suited for hardware implementation.

References

1. Bidarte, U., et al. "Adaptive Image Brightness and Contrast Enhancement Circuit for Real-Time Vision Systems," *IEEE Intl. Conf. on Industrial Technology* 2000, Vol. 1, pp 421-426.
2. Goh, K.H., et al. "Automatic Video Contrast Enhancement" *IEEE Intl. Symposium on Consumer Electronics* 2004, pp 359-364.
3. Park, H.W., et al. "A Novel Method for Image Contrast Enhancement in TFT-LCDs: Dynamic Gamma Control", *Proceedings of SID* 2003, pp 1343-1345.
4. Kim, Y., "Contrast Enhancement using Brightness preserving Bi-histogram equalization," *IEEE Transactions on Consumer Electronics* 1997, Vol. 43, Issue 1, pp 1-8.
5. Chen, S., et al. "Contrast Enhancement using Recursive Mean-Separate Histogram Equalization for Scalable Brightness Preservation", *IEEE Transactions on Consumer Electronics* 2003, Vol. 49, Issue 4, pp 1301-1309.
6. Zuiderveld, K., "Contrast Limited Adaptive Histogram Equalization," Chapter VIII.5, *Graphics Gems* IV, Cambridge, MA, Academic Press, 1994, pp 474-485
7. Srinivasan, S., et al. "Adaptive Histogram-Based Video Contrast Enhancement," *Patent Filing*, 2005
8. Russ, J., "*The Image Processing Handbook*," 4th ed., CRC Press, 2002