Dynamic Contrast Enhancement based on Histogram Specification

Chi-Chia Sun, Shanq-Jang Ruan, *Member,* IEEE, Mon-Chau Shie, *Member,* IEEE, and Tun-Wen Pai, *Member,* IEEE

Abstract — *In this paper, a novel contrast enhancement algorithm is proposed. The proposed approach enhances the contrast without losing the original histogram characteristics which is based on the Histogram Specification technique. It is expected to eliminate the annoying side effects effectively by using the differential information from the input histogram. The experimental results show that the proposed Dynamic Histogram Specification (DHS) algorithm not only keeps the original histogram shape features but also enhances the contrast effectively. Moreover, the DHS algorithm can be applied by simple hardware and processed in real-time system due to its simplicity*[1].

Index Terms — Contrast enhancement, histogram equalization, histogram specification, bi-histogram equalization, dynamic histogram specification, image enhancement.

I. INTRODUCTION

Contrast enhancement techniques are widely used for image/video processing to achieve wider dynamic range. Histogram modification based algorithm is the most popular approaches to achieve widely dynamic range. Histogram Equalization (HE) is one of the most commonly used algorithms to perform contrast enhancement due to its simplicity and effectiveness [1]. In general, the HE distributes pixel values uniformly and results in an enhanced image with linear cumulative histogram. Useful applications of HE enhancement include medical image processing, speech recognition and texture synthesis, which are usually employed with histogram modification [2]–[5].

In the past few years, there are several researches focused on image/video contrast enhancement [6]–[14]. Mean preserving Bi-Histogram Equalization (BBHE) was proposed to overcome the brightness preservation problems [7], [15]. BBHE separates the input image/video histogram into two parts based on input mean before equalizing them independently. Later, Equal Area Dualistic Sub-Image Histogram Equalization (DSIHE) was proposed to separate the histogram by entropy value [8]. Chen [9], [10] proposed an extension of BBHE which was referred to as Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) to provide maximal brightness preservation. Although the above algorithms can perform highest contrast enhancement in image/video signals, however, these algorithms actually result in more annoying side effects and will be discussed in the following sections.

In this paper, a novel Dynamic Histogram Specification (DHS) algorithm based on the Histogram Specification (HS) technique [1], [16], [17] is proposed to enhance the contrast without losing the original histogram characteristics. It is expected to eliminate the above drawbacks effectively. In order to keep original histogram features, the DHS extracts the differential information from the input histogram. On the other hand, it also applies extra parameters to control the overall processing, such as frame direct current and gain control value. By contrast, the proposed DHS algorithm not only leads more naturally than other algorithms which are based on the histogram modification, but also enhances the contrast effectively. It is worth noticing that the proposed DHS algorithm can be applied practically in electric appliances, especially in mobile handset due to its simplicity.

The paper is organized as follows. In section 2, we briefly introduce the theory of Histogram Equalization and Histogram Specification. We present the details of Dynamic Histogram Specification algorithm in section 3. In Section 4, we applied DHS to the video sequences and compared with other Histogram algorithms to show its effectiveness while section 5 concludes this paper.

II. HISTOGRAM EQUALIZATION AND HISTOGRAM SPECIFICATION THEORY

This section will briefly describe the definitions of the HE and HS, whose detailed definitions can be found in [1], [7], [9].

A. Histogram Equalization

In the following, only discrete cases will be considered. Let $F = X(x, y)$ denote a input frame which is composed of gray pixel levels in the range of $[0, L\text{-}1]$. The transformation function $C(r_k)$ in a input frame is defined as

$$s_k = C(r_k) = \sum_{i=0}^{k} P(r_i) = \sum_{i=0}^{k} \frac{n_i}{n} \qquad (1)$$
$$\text{where } 0 < s_k \leq 1 \text{ and } k = 0, 1, 2, \ldots, L - 1.$$

In Eq. (1), n_i represents the number of times that k^{th} gray level appears in F, and n is the total numbers of pixels in the input video frame. $P(r_i)$ is represented as the Probability Density Function (PDF) of the input gray level k. Based on the PDF, the Cumulative Density Function (CDF) is defined as $C(r_k)$. Consequently, the HE equalizes the histogram distribu-

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tion of input stream into its dynamic range by employing the CDF as a transform function which is defined as

$$F^{th} = \{ f(X(x, y)) \,|\, \forall\, X(x, y) \in F \}, \tag{2}$$

where $f(X)$ represents transform function and F^{th} denotes the frame number appeared in video sequences. Although the HE introduces a significant improvement in image/video contrast, it gives rise in more artifacts and undesirable side effects [7], [8].

B. Histogram Specification

Histogram Specification is a useful technique of histogram modification for image enhancement. Compared with the HE, the major difference is that it transforms the histogram of image into a specified histogram to achieve highlighted gray-level ranges. In this sense, the CDF of the specified histogram is defined as

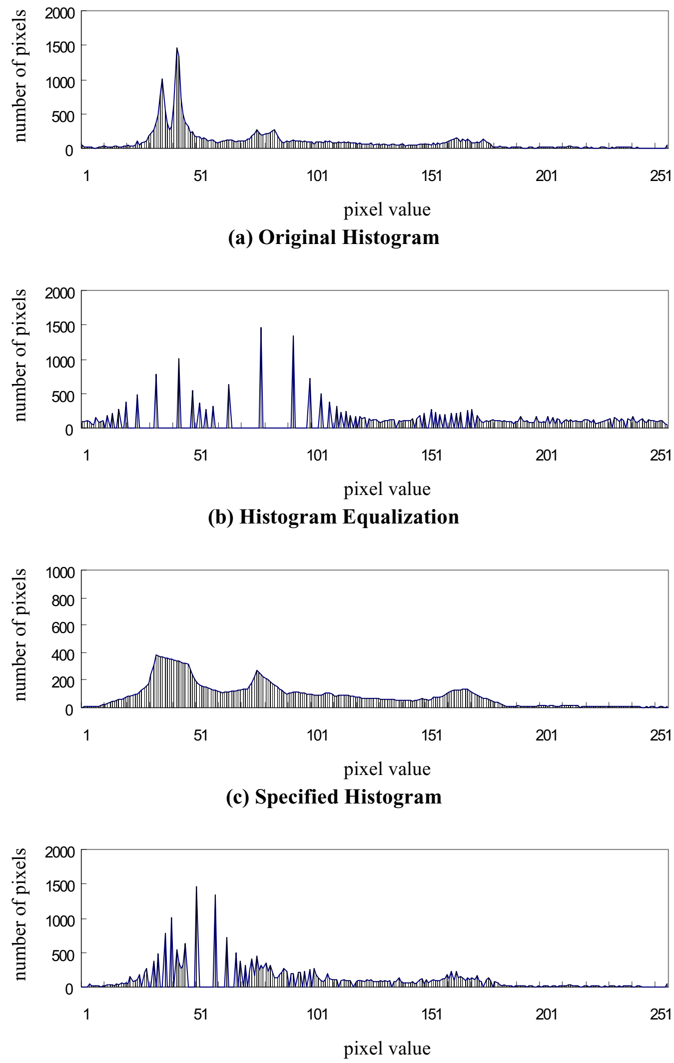
$$v_k = C(z_k) = \sum_{i=0}^{k} P(z_i) \quad \text{where } k = 0, 1, 2, \ldots, L-1. \tag{3}$$

$$\{ (C(z_k) - s_k) = (v_k - s_k) \} \rightarrow 0 \quad \text{where } k = 0, 1, 2, \ldots, L-1. \tag{4}$$

Here Eq. (3) represents a transformation for specified histogram of $P(z_i)$. Note that s_k and v_k represent the histogram of sequential input frame and the specified histogram respectively. As in the continuous case, we have to search the value of z_k which satisfy the Eq. (4). In other words, we have to find out the smallest integer number between v_k and s_k. Finally, the mapping table of the z_k will be the output of the Eq. (5).

$$z_k = C^{-1}(s_k) \quad \text{where } k = 0, 1, 2, \ldots, L-1. \tag{5}$$

Fig. 1 shows the histogram distributions of different algorithms. It can be easily observed from Fig. 1(b) that the HE distributes pixel values uniformly. On the other hand, we can specify the frame's histogram distribution directly by using a specified histogram, as shown in Fig. 1(d). However, there are no definite rules to determine the most suitable specified histogram table, especially for motion pictures. In this regard, in order to enhance the video content and reduce unwanted side effects, we propose an innovative algorithm called Dynamic histogram Specification (DHS) to accomplish these goals.



(a) Original Histogram

(b) Histogram Equalization

(c) Specified Histogram

(d) Histogram Specification

Fig. 1. Frame of histogram distribution.

III. DYNAMIC HISTOGRAM SPECIFICATION

A. Critical Points

In order to keep original histogram shape without losing its simple characteristics, the proposed DHS algorithm employs derivative operation to achieve this goal. The mathematical derivative model is defined as

$$\begin{aligned} D1 &= \frac{\partial f}{\partial k} = n_{k-1} - n_k, \\ D2 &= \frac{\partial^2 f}{\partial^2 k} = n_{k-1} + n_{k+1} - 2 * n_k, \\ &\text{where } k = 0, 1, 2, \ldots, L-1, \end{aligned} \tag{6}$$

where D1 and D2 represent 1^{st} and 2^{nd} derivatives results respectively. Eq. (6) can be implemented by simple hardware due to its simplicity.

Next, DHS algorithm collects the Critical Points (CPs) from 1^{st} and 2^{nd} derivative results for the reason to achieve dynamic contrast enhancement. Fig. 2 shows the pseudo-code of CPs algorithm. Notice that CPs are searched and determined by the following two rules. First, we search the CPs from 1*st* derivative results with a value which is greater than that of Contrast Gain Value. In the other words, the DHS will record the point where 1*st* derivative result is greater than gain value. Secondly, the zero crossing points are detected from 2*nd* derivative results. Then the DHS records these zero crossing points for the reason to maintain the original histogram distribution features.

PROCEDURE CPs_func(Gain) **IS**
  Input: Frame Histogram Table his = $(r_0, r_1, \ldots, r_{L\text{-}1})$
  Output: Specified Histogram Table CPs = $(z_0, z_1, \ldots, z_{L\text{-}1})$

BEGIN
  D1 = 1st derivative(his)
  D2 = 2nd derivative(D1)

  FOR *i* **IN** 0 **TO** *L*-1 **LOOP**
    IF $|D1_i|$ > Gain
      OR ($D1_i >$ 0) & ($D2_i <$ 0) & ($D1_i >$ 0) **THEN**
        CPs(*i*) = 1
    ELSE
        CPs(*i*) = 0
  END LOOP;

RETURN CPs;
END PROCEDURE;

Fig. 2. Algorithm to search Critical Points from 1st and 2nd derivative results. ($|D1_i|$ denotes the absolute value of 1st derivative.)

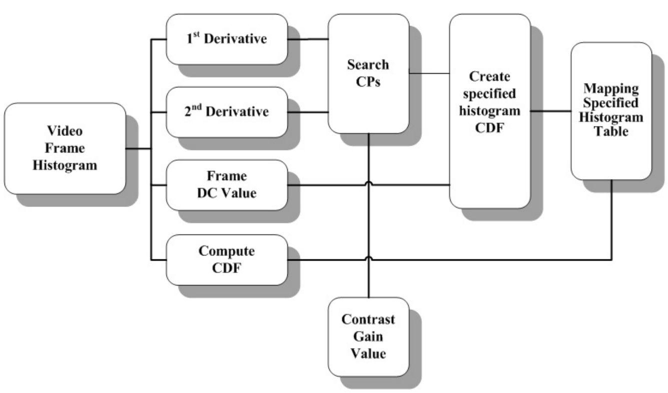


Fig. 3. The framework of the Dynamic Histogram Specification.

B. DHS algorithm

The functional block diagram for realization the proposed algorithm is shown in Fig. 3, and the algorithm of DHS is formally defined by following steps:

1. Calculating 1*st* and 2*nd* derivative from the input histogram table. Then computing the value of Direct Current (DC) and CDF (i.e. s_k) from the input frame sequentially.
2. Searching the Critical Points (CPs)[2] from the derivative results.
3. Combining the CPs with the DC Gain Value to construct the specified histogram CDF (i.e. v_k).
4. Finally, determining the mapping table of specified histogram by v_k and s_k according to the Eq. (4).

In step 1, the proposed algorithm first computes 1*st* and 2*nd* derivatives according to the Eq. (6). Moreover, the DC and CDF are also extracted from the input frame respectively. In step 2, the proposed DHS algorithm starts to collect CPs from the differential results by using the algorithm, as shown in Fig. 2. The DHS algorithm extracts the differential feature points from 1*st* and 2*nd* derivatives for the reason to keep the original histogram table characteristics. Next, DHS uses the CPs and DC values to generate the specified histogram CDF (i.e. v_k) by employing slope operation as shown in step 3. The specified algorithm is defined as

$$\begin{aligned} &\text{Slope} = \frac{\text{His}[k] - \text{His}[b]}{k - b} \\ &\text{Diff} = \text{His}[k] - \text{His}[b] \\ &\text{Matching}[k] = \text{His}[b] + \text{Diff} * \text{Slope} \\ &\qquad\qquad \text{where } k = 0, 1, 2, \ldots, L-1, \end{aligned} \tag{7}$$

where b denotes the recorded point which is appeared before the k in CPs, and Matching represents the specified histogram table. Therefore, the DHS can construct the specified histogram table by employing slope operation from CPs. At last step, the proposed algorithm uses the dynamic specified histogram CDF as the input of Histogram Specification (i.e. z_k) according to Eq. (5).

Finally, the DHS algorithm performs contrast enhancement dynamically depends on the video content, and Fig. 4 shows the pseudo code of the proposed DHS algorithm.

In next section, we will present the detailed experimental results to further display the effectiveness of the proposed algorithm.

PROCEDURE DHS_func( ) **IS**
  Input: Frame Histogram Table his = $(r_0, r_1, \ldots, r_{L\text{-}1})$
  Output: Specified Histogram Table CPs = $(z_0, z_1, \ldots, z_{L\text{-}1})$
BEGIN

  s_k = CDF_compute(his)
  DC = DC_compute(his)
  CPs = CPs_func(Gain)
  h_s = Create_func(Gain, his)
  v_k = CDF_compute(hs)
  out_i = Mapping(v_k, s_k)

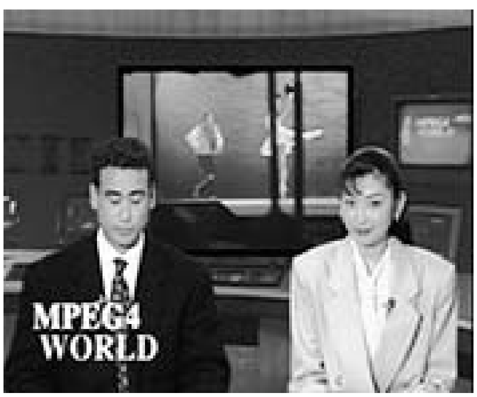
END PROCEDURE;

Fig. 4. Algorithm to perform Dynamic Histogram Specification.

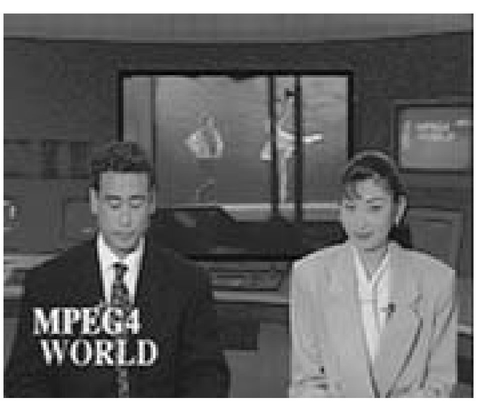
[2] The CPs denotes the behavior of derivatives during into and out of these histogram features.

(a) Original

(b)Histogram Equalization



(c) Bi-Histogram Equalization



(d) Dynamic Histogram Specification

Fig. 5. Evaluation results of “News” H.263 qcif pattern.

(a) Original

(b) Histogram Equalization

(c) Bi-Histogram Equalization

(d) Dynamic Histogram Specification

Fig. 6. Evaluation results with additional noise signal in the background.

IV. EXPERIMENTAL RESULTS

In order to demonstrate the performance of the proposed algorithm, we have simulated the HE, BHE and DHS with some well-known video sequences to further display the ability of the proposed approach. Fig. 5 shows the simulation results of HE, BHE and DHS. It can be easily observed from Fig. 5 that both HE and BHE reveal some annoyed effects, such as overhead brightness enhancement, white noise, and some unnatural results. While HE and BHE do provide great improvement in contrast enhancement, they can not be accepted by human visual sensitivity due to large artifacts they introduced. Next, Fig. 6 shows the simulation results with additional noise signal in the background to show the defects of highlighted noise. Apparently HE and BHE introduce more noise highlight than DHS as shown in Fig. 6(b) and 6(c) respectively. Moreover, there are another two simulation results as shown in Fig. 7 and 8 to further prove the performance of proposed algorithm. By contrast, the proposed contrast enhance algorithm DHS performs more naturally than the other ones obviously and also keeps the original histogram table shape efficiently.

(a) Original

(b) Histogram Equalization

(c) Bi-Histogram Equalization

(d) Dynamic Histogram Specification

Fig. 7. Evaluation results of "foreman" H.263 qcif pattern.

(a) Original

(b) Histogram equalization

(c) Bi-Histogram Equalization

(d) Dynamic Histogram Specification
Fig. 8. Evaluation results of "container" H.263 qcif pattern.

Due to its simple derivative operation, the DHS algorithm can be applied by simple hardware and processed in real-time system. In summary, the DHS algorithm provides a better choice to perform contrast enhancement, while reducing annoying effects, and maintaining original histogram distribution shape. Conclusion

V. CONCLUSION

In this paper, we proposed an innovative dynamic specific histogram algorithm to perform contrast enhancement. The experimental results clearly indicated that the proposed DHS algorithm not only keeps the original histogram distribution shape features but also enhances the contrast dynamically. It is perhaps surprising that a simple mathematically defined algorithm out performs other complex models so well, especially in noisy background. The success is due to its strong ability in measuring differential information during the processes. In summary, the proposed DHS algorithm can perform contrast enhancement, while reducing annoying effects, and keeping the original histogram distribution features. Furthermore, the simplicity of DHS can provide contrast enhancement capability in many electric appliances, such as mobile phone, digital camera, mobile handset, and especially in small LCD panel.

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