Thresholding Histogram Equalization

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The drawbacks of adaptive histogram equalization techniques are the loss of definition on the edges of the object and overenhancement of noise in the images. These drawbacks can be avoided if the noise is excluded in the equalization transformation function computation. A method has been developed to separate the histogram into zones, each with its own equalization transformation. This method can be used to suppress the nonanatomic noise and enhance only certain parts of the object. This method can be combined with other adaptive histogram equalization techniques. Preliminary results indicate that this method can produce images with superior contrast. Copyright © 2001 by W.B. Saunders Company

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THE INTENSITY WINDOWING technique is a widely used method for image enhancement when the image information is presented in specific gray-level bands that are of interest to the observer. Information necessary to identify these useful bands often is not available a priori. In such cases, it is more practical to maximize the information conveyed from the images to the observer by distributing the display intensity range as uniformly as possible over the available gray-level bands. Histogram equalization (HE) allows each gray level to be represented by an approximately equal number of pixels and yields maximum entropy. Histogram equalization offers a substantial improvement for the displayed image.

VARIATION OF HISTOGRAM EQUALIZATION

The global histogram equalization¹ technique utilized the entire image to calculate the histogram. Sometimes it is necessary to enhance the details over a small region. The number of pixels in the region may have a negligible influence on the

histogram computation, and the transformation will not have the desired local enhancement. One solution is to devise a transformation based on the gray-level distribution in that region. Adaptive histogram equalization (AHE) maximizes the contrast throughout an image by adaptively enhancing the contrast of each pixel relative to its local neighborhood.² It uses a local histogram of the surrounding neighborhood to calculate the transformation of each pixel. The AHE method offers optimal enhancement of the local contrast as the entire available gray-level range is applied to each local neighborhood. However, this method causes overenhancement of the nonanatomic noise, which might have a higher intensity level than the interior of the object.

The contrast-limited adaptive histogram equalization technique (CLAHE) is a special class of AHE.³ In CLAHE, the histogram is clipped to a predefined level, and the excess counts are redistributed among the other intensities before the cumulative distribution function (CDF) computation. Clipping is used to control the steepness of the enhancing transformation, and, as a result, the noise overenhancement in the images can be alleviated.

Although histogram equalization can enhance the contrast, it reduces the number of gray levels in the processed image, resulting in a loss of information entropy. Fu et al⁴ applied a wavelet transform on the equalized images to fine tune the gray-level distribution to a more even shape. As a result, the loss of information was compensated.

CLINICAL APPLICATION OF HISTOGRAM EQUALIZATION

The usefulness of histogram equalization has been verified in several clinical applications. Braunstein et al⁵ applied AHE to plain radiographs of bone lesions and found that the equalized images were superior to nonequalized images in cortical breakthrough determination and the presence or absence of periosteal reactions. Pisano et al^{6,7} compared various display algorithms to enhance the contrast in digital mammography for diagnosis and screening. They concluded that CLAHE can provide subtle edge information but might degrade the performance in the screening setting by en-

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hancing the visibility of nuisance information. Rehm et al⁸ designed an artifact-suppressed AHE technique for the display of chest radiographs. In radiation therapy, the outcome of the treatment depends largely on the accurate positioning of the geometrical setup, which can be verified using a portal imaging device. Because of the high energy of the x-ray beam from the linear accelerator, the contrast is very poor in portal images. AHE techniques are known to be effective for the enhancement of contrast in portal images.⁹

DRAWBACKS OF HISTOGRAM EQUALIZATION

Leszczynski et al¹⁰ analyzed the transformation of pixels near the edge of the treatment field in portal images. They found that the difficulties in field edge reproduction is caused primarily by the significant reduction in edge contrasts as well as the overenhancement of the nonanatomic backgrounds, which primarily are noise. When processed by CLAHE, because of the local transformation characteristic, the noise was overenhanced with respect to signal. Leszczynski et al¹⁰ used an edge-extracting algorithm to delineate the treatment field contour in portal images. The AHE then is applied selectively to the region. A combination of edge detection and selective enhancement was shown to produce images with superior contrast on a patient's anatomic features. However, because of the poor contrast of the portal images, treatment field segmentation is not an easy task.

We propose a simple solution to exclude noisy pixels from the CDF computation based on intensity thresholding.

GLOBAL HISTOGRAM EQUALIZATION

The contrast-enhancing transformation in global histogram equalization is defined as being directly proportional to the CDF:

$$I(x,y) = I_m \times \text{CDF}(f[x,y]) \quad (1)$$

where $f(x,y)$ and $I(x,y)$ are the original and the transformed pixel intensity, respectively and I_m is the maximum intensity of the display device. The CDF is obtained by integrating the histogram of the original image, ie,

$$\text{CDF}(r) = \sum_{w=0}^r P(w) \quad (2)$$

where $P(w)$ is the histogram representing the probability of occurrence of gray level w . This form of transformation allows each gray level to be represented by an approximately equal number of pixels.

THRESHOLDING HISTOGRAM EQUALIZATION

In the proposed method, the histogram is divided into zones according to the gray level. Each zone will map to a display intensity range using a different enhancement transformation. Figure 1 shows a typical CDF and a zone specified by the gray-level range (G_i, G_j) to be mapped into intensity range (I_i, I_j). The transformation for the gray-level $f(x,y)$ between (G_i, G_j) is defined as:

$$I(x,y) = I_i + (I_j - I_i) \frac{\text{CDF}(f[x,y]) - \text{CDF}(G_i)}{\text{CDF}(G_j) - \text{CDF}(G_i)} \quad (3)$$

If the total number of zone is equal to 2, this becomes a thresholding technique when G_i is set to a threshold value and I_i to a small intensity. Pixels with gray level less than the threshold value will be suppressed, whereas the other pixels will be enhanced to a greater display range.

RESULTS AND DISCUSSION

A computed tomography (CT) image and portal image were used to test the new method. Both images possess a large nonanatomic area. The images were subsampled to 256×256 for fast computing. The window size for the adaptive processing was 15×15 .

Fig 1. The cumulative distribution function and its zoning transformation.

Fig 2. (a) Original CT image and its processed images using (b) intensity windowing, (c) global histogram equalization, (d) adaptive histogram equalization, (e) CLAHE (clipping level, 5), (f) thresholding CLAHE (clipping level, 5), and (g) median filtering (3×3) before CLAHE (clipping level, 5).

CT Image

Figure 2 shows the original CT image of a head and the results from using various histogram equalization techniques. The contrast in the brain tissue

(Fig 2a) is very low. The intensity windowing (Fig 2b) does not enhance both soft tissue and bony structure at the same time. The result of global histogram equalization (Fig 2c) shows a slight improvement in contrast enhancement. The AHE algorithm improves the contrast, but the noise also is enhanced (Fig 2d). The noise in the resultant CLAHE algorithm image (Fig 2e) is smoothed out, but still generates unpleasant viewing perception. The thresholding CLAHE algorithm completely suppresses the noise, as shown in Fig 2f.

Portal Image

Figure 3a shows an original portal image of a head. Figures 3b and 3c are CLAHE process results using a clipping level equal to 5 and 15, respectively. It can be seen that CLAHE with a smaller clipping level suppresses more noise with the sacrifice of contrast enhancement. The CLAHE (clipping level, 15) with thresholding eliminates the noise while maintaining the contrast enhancement (Fig 3d).

Discussion

To avoid the noise overenhancement in histogram equalization technique, it is instinctive to preprocess the image with a median filter. Fig 2g shows the result of applying a 3×3 median filter

Fig 3. (a) Original portal image and its processed images using (b) CLAHE (clipping level, 5), (c) CLAHE (clipping level, 15), and (d) CLAHE (clipping level, 15) with thresholding.

before the CLAHE technique. Although it smoothes out noisy background, some detailed information also is lost. A similar result is obtained if the median filter is applied after CLAHE.

CLAHE is very effective in enhancing contrast but creates an annoying and possibly less diagnostic image. In this situation, thresholding can be used to eliminate the noisy pixels with gray levels less than the threshold value. The rest of the image will not be affected. Thresholding CLAHE is not limited to suppressing noisy dark backgrounds. It also can remove selectively regions within a specified intensity zone, eg, a bright overexposed area. However, it has to be performed with caution,

because some useful signal might be removed as well.

SUMMARY

Adaptive histogram equalization successfully improves images of the human internal anatomy. Its usefulness is limited due to the over enhancement of the noise. A method was developed to eliminate the noisy area from histogram calculation using intensity thresholding. This method is most suitable for images with a large nonanatomic noisy background. The proposed method can be incorporated into other AHE techniques. This method was tested on a number of clinical images.

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