Image contrast enhancement based on the generalized histogram

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Abstract

◆ Proposed scheme
  – An adaptive contrast enhancement method
  – Basing the generalized histogram
    • Obtainment by relaxing the restriction of using the integer count

◆ Integer count
  – Fractional count
    • Use for increasing the contrast gain of its intensity level
  – Remainder count
Introduction

◆ Conventional methods
  – Generating the mapping function based on the histogram
  – The most common way to enhance image contrast
    • The intensity mapping
      – Reassigning the intensity through a monotonically increasing function
      – Local histogram equalization as one of the most popular methods
  – Local histogram equalization method
    • Use in various fields
    • Producing the unnatural appearances resulting from contrast overenhancement
      – Especially in homogeneous regions
    • Attempt to amplify the contrast for every pixel as much as possible
    • To overcome the limitation
      – Having the numerous methods proposed by modifying the histogram
Proposed method

- A new contrast enhancement method based on the generalized histogram by relaxing the restriction of using the integer count of the histogram

- In generating the generalized histogram
  - Splitting the count allocated to each pixel into the fractional count and the remainder count
  - Obtaining the generalized histogram by accumulating the fractional count for each intensity level
  - Distributing the remainder count uniformly over the intensity levels

- A result
  - Visually more pleasing results than the conventional local histogram equalization
Process

– In section 2
  • Description of the intensity mapping using the contrast gain function
  • Reviewing the local histogram equalization method
– In section 3
  • Introducing the generalized histogram
  • Proposing a scheme that generates the fractional count for each pixel according to its regional characteristics and user’s requirement
– In section 4
  • Presentation of the experimental results
– Finally, section 5
  • conclusion
Intensity mapping methods

- Generation of the output intensity $y_{ij}$ by mapping the input intensity level $x_{ij}$ through a mapping function $f_{ij}(\cdot)$

$$y_{ij} = f_{ij}(x_{ij}) \quad (1)$$

- Classification into global and local methods
  - Global methods
    - Applying just one mapping function for every pixel
    - Representation as $f(\cdot)$
  - Local methods
    - Applying different mapping functions for different pixels
    - Representation as $f_{ij}(\cdot)$
    - Determination for each pixel using the information of the pixels within the local region surrounding the target pixel at $(i, j)$
Contrast gain function $w_{ij}(\cdot)$

- The slope of the mapping function at an intensity level
  - Indication of the amount of contrast enhancement for that level
- Using the discrete derivative, $df(k) / dk$

$$w_{ij}(k) = \begin{cases} f_{ij}(0), & k = 0, \\ \frac{df_{ij}(k)}{dk} & = f_{ij}(k) - f_{ij}(k-1), & k = 1, \ldots, Q-1, \end{cases}$$

(2)

Where $Q$ represents the number of intensity levels

- $f_{ij}(\cdot)$ readily obtained by $w_{ij}(\cdot)$

$$f_{ij}(k) = \sum_{l=0}^{k} w_{ij}(l), \quad k = 0, 1, \ldots, Q-1$$

(3)
– Contrast gain function of local histogram equalization
  • Obtaining by normalizing the histogram of the local region

\[ w_{ij}(k) = \frac{1}{N_{ij}} h_{ij}(k), \quad k = 0, 1, \ldots, Q-1 \]  \hspace{1cm} (4)

Where \( h_{ij}(\cdot) \) denotes the histogram of the local region
\( N_{ij} \) represents the number of pixels in the local region

◆ The local region \( A_{ij} \)
  – A square window centered at the target pixel
  – The histogram

\[ h_{ij}(k) = \sum_{(u,v) \in A_{ij}} \delta(x_{uv},k), \quad k = 0, 1, \ldots, Q-1 \]  \hspace{1cm} (5)

Where \( \delta(k,l) \) represents the Kronecker delta function,
which equals 1 if \( k = l \) and equals 0 otherwise
– The equal increment of the contrast gain for every pixel
  • Causing the contrast overenhancement about the large number of pixels with an intensity level
  • Causing a small contrast gain for the human observers
– The result of local histogram equalization
  • No satisfaction for various situations
Adaptive Contrast Enhancement Based on the Generalized Histogram

- **Generalized Histogram** $g_{ij}(k)$
  - Replacement of the histogram $h_j(k)$ in (4)
  - Splitting the integer count allocated to the pixel at $(u, v)$ within the local region $A_j$
    - Use of the fractional count for increasing $g_{ij}(k)$
      - The adaptive reduction of the excessive increment of the contrast gain
    - Distribution of the remainder count in the manner that preserves the image contrast
  - The uniform distribution of the remainder count
    - Implying a contrast gain function
    - Generating the same contrast gain for all intensity levels and producing the contrast preservation
– The generalized histogram $g_{ij}(k)$ of the local region $A_{ij}$ as a result

$$g_{ij}(k) = \sum_{(u,v) \in A_{ij}} \left( r_{uv} \cdot \delta(x_{uv}, k) + (1-r_{uv}) \cdot \frac{1}{Q} \right),$$

$$k = 0, 1, \ldots, Q-1$$

(6)

Where $r_{uv}$ denotes the fractional count for a pixel at $(u, v)$

• The fraction count assigned for contrast enhancement by increasing the contrast gain of its intensity level
• The uniformly distributed remainder count for the contrast preservation

– The range of the fractional count

• Having a part of count, 1
• If $r_{uv} = 1$ for every pixel in the image
  – Having same value between the $h_j(k)$ and $g_j(k)$

– Controlling the proportion of contrast enhancing to contrast preserving by adjusting the value of $r_{uv}$
Generating the Fractional Count

- Aim
  - Explaining a method of obtaining an appropriate fractional count for visually pleasing results depending on the regional characteristics of the pixel and the purpose of applications

- The contrast gain
  - Adjustment according to the purpose of the application
  - For example
    - Large contrast gains over the whole image for inspecting scientific images
    - Small contrast gains for enhancing photographic images
  - Adjustment according to its spatial activity
    - The rate of intensity changes
– The degree of relaxation in the contrast gain
  • Depending on the value of $r_{uv}$
– The fractional count $r_{uv}$
  • Adjustment according to both the purpose of applications and the spatial activity of the pixel at $(u,v)$

$$r_{uv} = \alpha \cdot \psi_{uv} \quad (7)$$

Where $\alpha$ and $\psi_{uv}$ reflect the user’s requirement depending on the application and the spatial activity of the pixel at $(u,v)$ respectively

• The first term, $\alpha$
  – Parameter controlled by the user
  – Controlling the amount of contrast enhancement over the whole image depending on the application and user’s taste
• The second term, \( \psi_{uv} \)
  – Adjustment of the contrast gain pixel by pixel according to its spatial activity
  – Estimation as using various measures such as the variance of \( x_{uv} \)

– The spatial activity
  • The average absolute difference normalized by the local mean

\[
S_{uv} = \frac{1}{8} \cdot \frac{\sum_{n=u-1}^{u+1} \sum_{m=v-1}^{v+1} |x_{nm} - x_{uv}|}{\frac{1}{9} \cdot \sum_{n=u-1}^{u+1} \sum_{m=v-1}^{v+1} x_{nm}}
\]

(8)

Where
  The numerator denotes the average absolute difference from the adjacent pixels
  The denominator denotes the local mean of the 3 x 3 pixels
- The range of $\psi_{uv}$
  - [0, 1]
  - Proportional to the spatial activity
    
    $$\psi_{uv} = 1 - e^{-\gamma \cdot S_{uv}}$$  \hspace{1cm} (9)
    
    Where $\gamma$ determines the slope of the function and $\gamma \geq 0$
  - A difference in the spatial activity by the value of increased $\gamma$
    - Producing a greater change in $\psi_{uv}$
    - Resulting in a greater change in the contrast gain
- The fractional count $r_{uv}$ as a result
  
  $$r_{uv} = \alpha \cdot (1 - e^{-\gamma \cdot S_{uv}})$$  \hspace{1cm} (10)
  
  Where $\alpha$ and $\gamma$ are two parameters with which users can control the degree
  of contrast enhancement depending on situations.
Experimental Results

◆ The test to verify the efficacy of the proposed method
  – The conventional local histogram equalization
    • Obtaining the good results for many images
    • Causing the contrast over-enhancement for the images
      – Including locally homogeneous regions such as the background
  – The proposed method
    • Generating the visually pleasing results by adjusting the contrast gain according to the regional characteristics
  – An example
    • The results from the building image in Fig.1.
Fig. 1. Contrast enhancement results with the 512x512 building image. (a) Original image, (b) result of global histogram equalization, (c) result of local histogram equalization, (d) result of the proposed method.
• The original building image (Fig. 1(a))
  – Having $512 \times 512$ pixels
  – Digitization to 8 bits, that is to say, $Q = 256$

• The resulting image of global histogram equalization (Fig. 1(b))
  – The somewhat enhanced contrast over the whole image
  – Degradation of the contrast of the details in the small regions
    » Such as the cars in the bottom of the image

• The resulting image of local histogram equalization (Fig. 1(c))
  – A $41 \times 41$ square window
  – Enhancement of the contrast of the details in the small regions
  – Quite unnatural image to human observers due to excessive amplification

• The result of the proposed method (Fig. 1(d))
  – Use with $\alpha = 0.6$ and $\gamma = 5$
  – Enhancement of the contrast of small details without radical change of visual impression
Fig. 2. The histogram and the generalized histogram for \( A_{195,355} \) in the building image. (a) An example local region, \( A_{195,355} \), (b) \( h_g(k) \) and \( g_g(k) \) for \( A_{195,355} \).
Analysis of the results for an example local region

- Showing the high values of the $h_y(k)$ for around the 240 intensity level
- High values of $h_y(k)$ around $k = 240$
  - Causing the strong contrast stretching in the result of local histogram equalization (Fig. 1(c))
- The $g_y(k)$ for around the 240 intensity level
  - Far smaller than the $h_y(k)$ for the corresponding intensity levels
  - Because the small signal activities of most pixels in the sky
- A result
  - Having the less changed intensity levels of the pixels in the sky in the result of the proposed method (Fig. 1(d))
  - Preserving the appearance of the image after applying the proposed method
Fig. 3. Contrast enhancement results with the 512×512 harbor image. (a) Original image, (b) result of global histogram equalization, (c) result of local histogram equalization, (d) result of the proposed method.
– An additional experimental result (Fig. 3.)
  • The original harbor image (Fig. 3(a))
    – 512×512 pixels and $Q = 256$
  • A result
    – Concluding that the proposed method produces visually pleasing contrast enhancement

◆ The amount of contrast enhancement
  – Determination by the fractional count $r_{uv}$ for each pixel
  – If $r_{uv}$ has the maximum value 1 for all pixels in the image
    • Having the same result for the generalized and conventional histogram
    • Reduction to the local histogram equalization about the proposed method
– When $r_{uv} = 0$ for all pixels in the image
  • Having the uniform distribution about the generalized histogram
    – Preserving the contrast
– Results with a varying degree of contrast by adjusting $r_{uv}$ in the proposed method
  • Determination of the value of $r_{uv}$ from $\alpha$ and $\gamma$
  • $\alpha$
    – Adjustment of the value of $r_{uv}$ over the whole image according to user’s requirement
  • $\gamma$
    – Determination of the relationship between the fractional count for a pixel and its spatial activity
– The effect of variation of $\alpha$ and $\gamma$
  • Results from the building image (Fig. 4)
    – Control of the amount of contrast enhancement over the whole image by adjusting the value of $\alpha$
    – Reflection of the increment of the contrast gain pixel by pixel according to the spatial activity by adjusting the value of $\gamma$
    – A difference in the spatial activity as $\gamma$ increases
      » Producing a greater change in the contrast gain
  – Selecting the size and the shape of the local region for each pixel
    • An actively studied issue
    • Conducting a number of research on finding a better local region for each pixel than a simple square window with a fixed size
    • For simplicity
      – Employing a square window with a fixed size in this paper
Fig. 4. Results of the proposed method with various $\alpha$ and $\gamma$. The value of $\alpha$ increases from left to right and the value of $\gamma$ increases from top to bottom. (a) $\alpha=0.3$, $\gamma=1$, (b) $\alpha=0.6$, $\gamma=1$, (c) $\alpha=1$, $\gamma=1$, (d) $\alpha=0.3$, $\gamma=5$, (e) $\alpha=0.6$, $\gamma=5$, (f) $\alpha=1$, $\gamma=5$, (g) $\alpha=0.3$, $\gamma=30$, (h) $\alpha=0.6$, $\gamma=30$, (i) $\alpha=1$, $\gamma=30$. 
Conclusion

◆ Proposed method
  - A novel contrast enhancement method using the generalized histogram

◆ Results
  - Control to the human observers for the amount of contrast enhancement
    • By adjusting the fractional count for each pixel according to user’s requirement and its spatial activity
  - Achieving the visually more pleasing contrast enhancement that the conventional histogram equalization methods
  - Verification for the efficacy of the proposed method through experiments