A Rule-Based Expert System for High-Quality Image Enhancement

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ABSTRACT: This paper presents a rule-based expert system for the enhancement of image contrast. Firstly, an input image is divided into several block subimages and the mean and variance transformation of each subimage are applied based on such rules. Secondly,based on the Gaussian overlay image recombination scheme, the enhanced subimages are recombined together into a high-quality output image which will be devoid of defect where the subimages are connected. This paper puts emphases on the discussion of the mean and variance transformation, the establishment and modification of the rule base, and the localized enhancement technique of the block subimages. The experimental results demonstrate that the rule-based method is superior to most traditional ones.
KEY WORDS: Expert System, Image Quality, Enhancement

Nowadays, there are many algorithms for contrast enhancement. In the use of them, the common problem faced is how to determine parameters in tranformation. Different selection of parameters will result in defferent enhancement effects, and therefore the selection of parameters depends on the properties of image to be processed. In the past, the method of "probing" was used for the selection of parameters in image processing. As it is troublesome and short of memory function, the "probing" procedure is always repeated in processing images of the same properties.

In this paper a rule-based expert system for contrast enhancement is presented. An initial rule base is constructed by the image processing knowledge of man on the basis of the mean and variance transformation. After that, the initial rule base is modified according to the expert evaluation on the experiment results for images of various properties. Thus, a rule base of expert knowledge is formed. In practice, repetition of probing for the selection of parameters is avoided and an image can be enhanced as expert expects by using rule-based contrast enhancement.

In order to enhance the image which is strongly dependent on the spatial variation of scene illumination, the establishment of a rule base for localized enhancement and the method of eliminating the border effect resulted from localized enhancement between block subimages are also discussed in this paper.

MEAN AND VARIANCE TRANSFORMATION

Mean and variance transformation is to transform the mean and variance of a source image into those of an expected image so as to attain the goal of enhancing image. The mathematical expressions are illustrated as follows.

Let $I_s(i,j)$, M_s and V_s indicate the grey level of a pixel at the position(i,j), mean and variance of the source image I_s respectively. $I_o(i,j)$, M_o and V_o indicate the grey level of a pixel at (i,j), mean and varcance of expected output image I_o respectively, where $i=1,2,\cdots M$, $j=1,2,\cdots N$.

Suppose $I_o(i,j)=A\cdot I_s(i,j)+B$ (1)

because $$M_s=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}I_s(i,j) \quad (2)$$

$$V_s=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}I_s^2(i,j)-M_s^2 \quad (3)$$

then:

$$M_o=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=0}^{N}I_o(i,j)=A\cdot M_s+B \quad (4)$$

$$V_o=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}I_o^2(i,j)-M_o^2=A^2\cdot V_s \quad (5)$$

from(4) and(5), we get

$$A=\sqrt{V_o/V_s}, \quad B=M_o-M_s\cdot\sqrt{V_o/V_s}$$

then (1) can be rewrited as

$$I(i,j)=\sqrt{V_o/V_s}\cdot I_s(i,j)+M_o-M_s\sqrt{V_o/V_s} \quad (6)$$

equation (6) is transformation relation between the grey level of input image Is and that of output image Io. The transformation function curve is illustrated in Fig1.

$I_{S1}=M_S-M_o\cdot\sqrt{V_S/V_o}$

$I_{S2}=M_S+(255-M_s)\cdot\sqrt{V_S/V_o}$

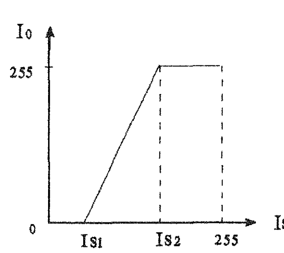


Fig1.

The contrast enhancement with mean and variance thansformation has following advantages: 1. It is a linear transformation. 2. The restraint role of a few limit grey levels can be eliminated so that the contrast enhance effect can be improved as a whole. 3. The transformation effect depends on the selection of new mean and variance mainly, and the relation between the new/old mean and variance is invariant basically, therefore the kind of images can be processed effectively if only the regularity mentioned above has been found.

ESTABLISHMENT AND MODIFICATION OF A RULE BASE

The function of rules is to acquire the expected new mean and variance on the basis of the image fact bases. The rules are invariant with input image, i. e., independent of input image. The establishment and modification of rules are based on man' s knowledge and the analysis of processing results for various images.

As is well known, if the mean of a image with grey range[0,255] is nearly equal to the center value 128 and the variance is large, the image must be very clear. Therefore, it is unnecessary for the image to be enhanced, i.e.,the mean and variance of the image are kept unvaried. Otherwise, the mean of a source image should be transformed nearly to 128, and the variance be enlarged. Based on the above idea, a rule base can be established.

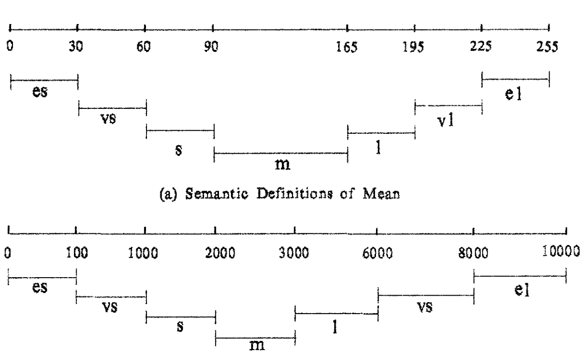
The mean and variance range is divided into 7 regions respectively, which are expressed with semantics as shown in Fig.2. Then, 49 rules in all are generated based on the different combination of the means and variances. The format of a rule is "IF ··· THEN ··· ". For example,

enhancement rule 10:

IF: (1) M_s is vs, (2) V_s is s

THEN: (1) $M_o=M_s\cdot 1.5+30$, (2) $V_o=V_s\cdot 3+1500$

The semantics of vs and s are shown in Fig. 2. Now, the frame of a rule base has been formed.



(a) Semantic Definitions of Mean

Fig .2 (b) Semantic Definition of Variance

In practice, the best enhancement effect may not be sometimes achieved by the mean and variance transformation based on the rules above. Therefore, it is necessary to modify the rules according to the analysis of image processing results.

In the rule base, the transformation relation between the mean and variance of output image and those of source image is

$$\left.\begin{aligned} M_o &= M_s\cdot a + C_1 \\ V_o &= V_s\cdot b + C_2 \end{aligned}\right\} \quad (7)$$

where C_1, C_2 are constants, a, b are modifiable parameters. The procedure of solving the modifiable parameters according to the best result acquired by interactive method is given as follows:

(1) Apply the mean and variance transformation to an image based on the initial rule base.

(2) Display the enhanced image and the curve of Fig.1 (including the values of I_{s1} and I_{s2})

(3) Answer the question: "Are you satisfied with the enhanced image? " If yes, goto(8). Otherwise,

(4) Indication: "If to increase (or decrease) the saturation of low grey levels, increase(or decrease) I_{s1}. If to increase(or decrease) the saturation of high grey levels, decrease(or increase) I_{s2}. Input I_{s1} and I_{s2}."

(5) Solve Mo and Vo with I_{s1} and I_{s2} input:

$$\left.\begin{aligned} M_o &= \left(\frac{255}{I_{s2}-I_{s1}}\right)(M_s - I_{s1}) \\ V_o &= \left(\frac{255}{I_{s2}-I_{s1}}\right)^2 V_s \end{aligned}\right\} \quad (8)$$

(6) Apply the mean and variance transformation based on the modified Mo and Vo.

(7) Goto (2)

(8) Answer the question: " Modify the rule base or not?" If no, goto (9). Otherwise, modify the parameters a and b of corresponding rule in rule base as follows:

$$\left.\begin{aligned} a &= \frac{1}{M_s}\left[\left(\frac{255}{I_{s2}-I_{s1}}\right)(M_s-I_{s1}) - C_1\right] \\ b &= \left(\frac{255}{I_{s2}-I_{s1}}\right)^2 - \frac{C_2}{V_s} \end{aligned}\right\} \quad (9)$$

(9) End.

RULE-BASED LOCALIZED IMAGE ENHANCEMENT TECHNIQUE

When an input image has strong spatially dependent variation in scene illumination, the mean and variance transformation illustrated above based on the global information over an entire image can not obtain high-quality output images. For this reason, a powerful and elegant localized image enhancement technique is presented in this paper.

The scheme of the localized image enhancement technique is illustrated as follows: (1) Divide an input image into several block subimages, e. g., 25 block subimages as shown in Fig.3(c) (2)Apply the mean and variance transformation to each block image. The new mean and variance of each block image are determined by a rule base. (3) Recombine the enhanced block images together into a high quality output image free of border effect, based on a Gaussian image overlay scheme.

The purpose of localized enhancement is to improve the local brightness of an image. The difference between local and entire image enhancement is that when local image enhancement is applied, we must take into consideration some a priori knowledge,e.g.,if the mean and variance of a block image are small, the block image must be very dark region of input image, and probably is the background of a scene, then it doesn' t have to be enhanced. In order that both local and entire image

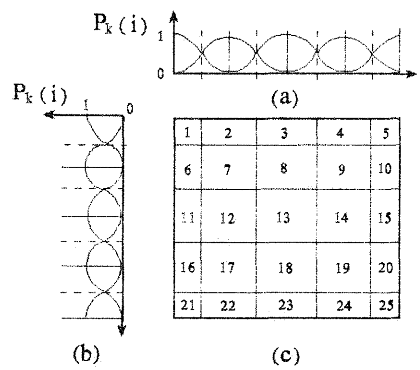


Fig.3

enhancement use a rule base for new/old mean and variance transformation, a judgement rule base is necessary, which is only used for local image enhancement to judge whether the mean and variance transformation are applied to a block image or not. If the mean and varicance range are divided into 5 regions respectively as shown in Fig. 4, then we can acquire 14 rules. For example,

judgement rule 1:

IF: (1)the mean is vs, (2) the variance is s

THEH: keep the block image unchanged

In order to eliminate the border effect resulted from localized enhancement between block images, a Gaussian image overlay technique is proposed.

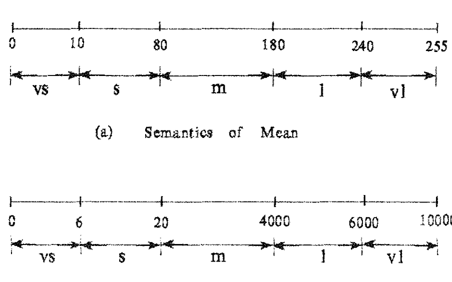
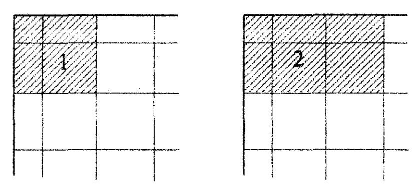


Fig.4

The so-called Gaussian overlay image technique is to acquire overlay block subimages based on the overlay block structure as shown in Fig. 5. If an image is divided into 25 subimages, 25 overlay-block images can be acquired. Each overlay-block image is the union of corresponding block subimage with its eight-neighboring block subimages in Fig. 3(c).If the subimage is situated at the corner or on the border of an image, the overlay-block image is the union of corresponding block subimage with its three or five neighboring block subimages. Then, 2-dimensional Gaussian spatial weighting function is applied to compute again the new/old mean and variance for each pixel in the mean and variance transformation. The Gaussian spatial weigting funtion is

$$P_k(i,j)=Exp\{-[(i-i_k)^2+(j-j_k)^2]/2\sigma^2\} \qquad (10)$$

where (i,j) is the coodinate of pixel, (i_k,j_k) is the center point coodinate of block image k in overlay-block image, σ^2 is variance. The center point and variance are illustrated in Fig. 3(a) and Fig.3(b).

Fig.5


EXPERIMENTAL RESULTS AND CONCLUSIONS

Fig. 6(a) is a 480-by-512 pixel image with a grey level range[0,255], of which the grey levels so heavily on low and high levels that many mini scenes cannot be distinguished. We have enhanced the original image applying tranditional image enhancement algorithms, e. g., histogram equalization, logarithm stretch and piecewise linear stretch, and the rule-based localized image enhancement technique presented in this paper, respectively. For the limitation of this paper here is only given the experimental result of histogram equalization. The results demonstrate that the best effect is acquired by applying the rule-based localized image enhancement technique, and the border effect is eliminated completely.

The technique presented in this paper carries out the task of automated selecting parameter quite well in image contrast enhancement. Because the human being knowledge about image enhancement technique and the expert evalution of enhanced image have been summarized to rules, which can be trained and modified. The benefits of the rule-based localized image enhancement techique are of high efficiency, stable performance, strong adaptability and best effect.

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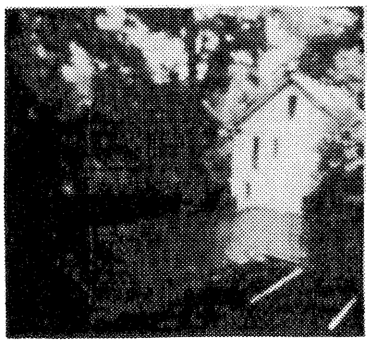
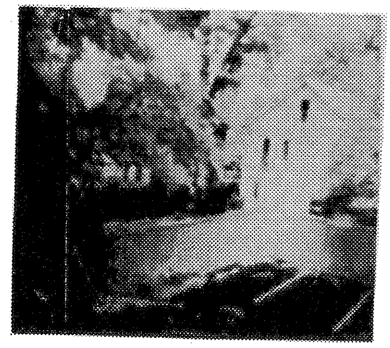
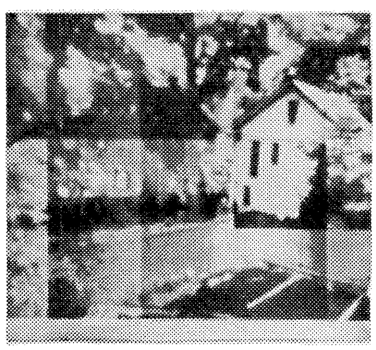


(a) Scene image before enhancement



(b) After histogram equalization enhancenment



(c) Middle result

The original input image was divided into 25 block subimages, and each subimage was enhanced with the rule-based localized scheme.

(d) Final output image

It was acquired by eliminating the border effects between block subimages from Fig.6 (c), based on a Gaussian image overlay recombination scheme.

Fig.6 A part of experimental results.