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IMAGE CONTRAST ENHANCEMENT METHOD BASED ON FUZZY LOGIC

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Abstract

This thesis analyzes fuzzy logic-based approaches for image contrast enhancement. Brightness differences between pixels are modeled using "IF-THEN" rules. Methods for enhancing contrast, reducing noise, and detecting contours using membership functions are explored. Fuzzy singletons, fuzzy inference systems, and defuzzification processes are highlighted as key components [3]. The cited approaches offer higher accuracy compared to classical methods. However, their computational complexity may be a limitation in resource-constrained systems.

Introduction

In the field of digital image processing, enhancing image quality, especially contrast enhancement, is an important task. Low-contrast images often lead to the misinterpretation of information in fields such as diagnostic analysis, artificial intelligence-based visual systems, medicine, and security. Therefore, contrast enhancement methods have always been a central focus of scientific research. Traditional methods such as gradient operators, statistical models, and filtration often fail to provide stable results for noisy images. In recent years, methods based on fuzzy set theory have emerged as an effective solution for image enhancement. These approaches involve stages such as expressing the dependency between pixels through "IF-THEN" rules, fuzzification, and defuzzification [4].

This thesis explores fuzzy logic-based approaches for improving image contrast, including fuzzy singletons, triangles affiliation functions, fuzzy inference systems and the FIRE paradigm based on working issued algorithms research the advantages and computational complexities of these methods are also studied.

In the picture pixels and their neighbors between brightness differences input , pixel brightness change and exit as This is a dependency . "IF-THEN" in the form of unclear rules with is represented by . If the image brightness values in the range [0, L-1] if , the interval [-L+ 1 , L-1] for triangle shaped unclear sets (positive , negative , zero) close) is selected . These sets based on structured of the rules to the result to look , to exit value is determined and original per pixel is added .

This approach of the image dark their places to open , to lighten parts and reduction through contrast improves . Especially the noise in reduction useful if pixel brightness surrounding average from the value more than if so , it is unclear average value with will be replaced .

To the image processing in giving often every one pixel surrounding points from the data used . Faint in the picture every one pixel unclear set as is considered.

Efficiency increase for , central pixel to the brightness relatively standard hard work is considered and local contrasts based on linear not been transformation function This function is created through image brightness will improve.

Membership functions are $\mu^f(x,y)$ and $\mu^g(x,y)$ as follows is defined as :

1. Normalization:

$$u(x,y) = l\,\frac{f(x,y) - f_{\min}}{f_{\max} - f_{\min}}.$$

2. Fuzzification:

$$\mu_i^f(x,y) = \frac{1}{1 + \dfrac{u(x,y) - c_i}{\sigma_f}},\ \ i = \overline{1,k}.$$

3. Defuzzification :

$$\mu_i^f(x,y) = \begin{cases} 2(\mu_i^f(\mathrm{x},\mathrm{y}))^2, & 0 \le \mu_i^f(\mathrm{x},\mathrm{y}) \le \dfrac{1}{2}, \\ 1 - 2(1 - \mu_i^f(\mathrm{x},\mathrm{y}))^2, & \dfrac{1}{2} < \mu_i^f(\mathrm{x},\mathrm{y}) \le 1. \end{cases}$$

4. Normalization:

$$v(x,y) = l\,\frac{g(x,y) - g_{\min}}{g_{\max} - g_{\min}}.$$

5. Fuzzification:

$$\mu_i^g(x,y) = \frac{1}{1 + \dfrac{v(x,y) - c_i}{\sigma_g}},\ \ i = \overline{1,k}.$$

6. Fuzzification clarification :

$$\mu_i^g(x,y) = \begin{cases} 2(\mu_i^g(\mathrm{x},\mathrm{y}))^2, & 0 \le \mu_i^g(\mathrm{x},\mathrm{y}) \le \dfrac{1}{2}, \\ 1 - 2(1 - \mu_i^g(\mathrm{x},\mathrm{y}))^2, & \dfrac{1}{2} < \mu_i^g(\mathrm{x},\mathrm{y}) \le 1. \end{cases}$$

This on the ground $f(x,y)$ and $g(x,y)$ of the image primary and again from work then suitable accordingly taken of the frame *(x , y)* at the point brightness values , x - row number and y column number ;

c_i , σ_f and σ_g - affiliation function parameters [5] .

Computer-generated images often have low contrast, meaning that the differences in brightness are small. In such images, shades of gray predominate rather than black and white. Increasing contrast means extending the brightness range of an image to its full scale. This can be done by **linearly transforming the image element by element.**

$$g(x,y) = af(x,y) + b,$$

that is, *a* and *b* are taken such that they reduce the fuzzy values of the brightness field to some standard magnitudes .

Given a grayscale image *A of size M × N* pixels, with gray level *r* between 0 and L-1. When using INT for image processing, they can be considered as an array of fuzzy singletons. Each array element is assigned a gray level according to predefined image properties such as brightness, sharpness, and uniformity. g_{ij} – *i* „*j* -th pixel suitable coming affiliation to the value $\mu_{\tilde{A}}(g_{ij})$ hint does .

As a generalization of this approach, the following image is included in an intuitively ambiguous environment:

$$A=\left\{\left\langle g_{ij},\ \mu_A(g_{ij}),\ \nu_A(g_{ij})\right\rangle \middle| g_{ij}\in\{0,\dots,L-1\}\right\},$$

this on the ground $i\in\{1,\dots,M\}$ *and* $j\in\{1,\dots,N\}$, $\mu_A(g_{ij})$ and $\nu_A(g_{ij})$ is suitable (*i*, j) -th pixel image properties appropriate to the collection affiliation and relevant not to be level indicates .

INT theory provide a flexible mathematical framework for dealing with "qualitative" features such as image contrast in the presence of non-uniformity and blurriness that are often found in digital images . Blur in images is caused by various factors. They affect our confidence in determining whether a pixel is “gray” or “sharp” and therefore cause some doubts about the corresponding point. Determining whether the A component, which describes the brightness of the image pixels, belongs to the INT is a simpler task that can be performed in the same way as in traditional fuzzy image processing systems. In the presented heuristic system, we consider the relationship of the gray level value *g to its normalized intensity level:*

$$\mu_A(g)=\frac{g}{L-1},$$

this on the ground $g\in\{0,\dots,L-1\}$. This emphasize It is necessary to use any other method of calculating μ_A possible .

We our selection is " gray" degree approximately *g* ” to equal the concept expression for conceptual in terms of suitable was symmetrical unclear numbers with Symmetric triangle unclear number as follows is determined

$$\mu_{\tilde{g}}(x)=\max\left\{0,1-\frac{|x-g|}{p}\right\},$$

where the positive parameter *p* controls the shape of the number.

Image blur is a measure of the grayscale ambiguity associated with image pixels. Sometimes, to increase the contrast between bright and dark areas, it is necessary to reduce the amount of blur in the image by several times. A contrast enhancement algorithm based on blur minimization is proposed in the following form:

$$\mu_{\tilde{A}}(g)=\left(1+\frac{g_{\max}-g}{F_d}\right)^{-F_e},$$

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here g_{max} represents the maximum gray level of the desired object, and F_e, F_d in a suitable position Exponential and denominational fuzzifiers that control the uncertainty in fuzzy planes are . The fuzzifier F_d is defined as follows:

$$F_d = \frac{g_{\max} - g}{\left(\frac{1}{2}\right)^{\frac{-1}{F_e}} - 1}.$$

After changing the affinity values, the defuzzifier is implemented as follows:

$$g' = \begin{cases} 0 & если\ \bar{g}' < 0, \\ \bar{g}' & если\ 0 \le \bar{g}' \le 255, \\ 255 & если\ \bar{g}' > 255, \end{cases}$$

here g' - new gray degree and $\bar{g}'$ reverse affiliation from the function harvest is done [6]:

$$\bar{g}' = g_{\max} - F_d \left((\mu'_A(g))^{\frac{-1}{F_e}} - 1 \right).$$

There are three main approaches to detecting the contours of objects in images: methods based on discrete derivatives, statistical analysis, and fuzzy set theory. Methods based on discrete derivatives use gradient and Laplace operators to detect contour points. Gradient operators find the maximum changes in first-order brightness, while Laplace operators highlight brightness discontinuities. However, Laplace operators are rarely used in practice due to their sensitivity to image noise.

Statistical approaches analyze the standard deviations of the brightness of neighboring elements at each pixel of the image. Based on this method, segmentation is performed, that is, the image is divided into identical areas and the contours are subsequently detected. However, this approach is computationally intensive actions demand does .

original image enhanced image

Fuzzy set theory-based approaches are characterized by their noise tolerance. For example, methods based on the FIRE (fuzzy inference ruled by else-action) paradigm detect contours through differences in gray levels of 3x3 size. In this, local features such as gradient, symmetry, and linearity are combined. Also, contours are found through maximum entropy. However, since these methods require a lot of computational resources, they are difficult to apply in real-time or resource-constrained practical systems. At the same time, it is necessary to create fuzzy system models, adapt them to real-world domains, and integrate them into a single intelligent system. integration issues still complete solution not found.

Conclusion

Fuzzy set theory-based approaches to image processing offer several advantages over classical gradient-based or statistical methods. In particular, fuzzy logic-based techniques yield effective results in critical tasks such as sharpening noisy images, enhancing contrast, and reliably detecting contours. Relationships between pixels are intuitively expressed through "if-then" rules, while brightness variations are modeled using triangular membership functions. Tools such as the FIRE paradigm, fuzzy singletons, membership, and inverse membership functions allow for a detailed analysis of the structural features of an image.

While these methods demonstrate significant benefits, their computational complexity is also a key consideration. This makes them challenging to implement in real-time or resource-constrained environments. Nevertheless, fuzzy set theory-based methods remain a promising direction for addressing issues such as non-uniformity, blurriness, and low contrast in images. Future research should focus on further optimizing these methods, adapting the models to various types of images, and integrating them into intelligent systems.

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