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Fuzzified Denoising Technique for Directional Total Variation Minimization on Color Image

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Abstract— **Image denoising refers to the recovery of a digital image that has been impure by the noise. Fuzzy systems concern basic methodology to represent and process uncertainty and imprecision in the linguistic information. Fuzzy image processing is the collection of all approaches that identify with, represent and process the images, their segments and features as fuzzy sets. The representation and processing depend on the selected fuzzy technique and on the problem to be solved. Total Variation (TV) is an isotropic image prior that penalizes the abrupt changes in the images in all directions. In this paper, we change TV so as to make it more suitable for images with a dominant direction. In most of the image denoising methods, the total variation denoising is directly performed on the noisy images. This paper combines the fuzzy logic function and directional total variation. The performance of the Directional Total variation is evaluated using the typical test images and the quality of the denoised images is assessed using a variety of objective metrics such as VSNR, SSIM and PSNR.**

Keywords- **Denoising, Fuzzy system, fuzzy logic, Directional Total Variation, VSNR, SSIM and PSNR.**

1. Introduction

Image preprocessing is an early stage activity in image processing that is used to prepare an input image for analysis to increase its usefulness. Image preprocessing includes image enhancement, registration and restoration. Noise is unnecessary signal that interferes with the original signal and degrades the visual quality of digital image. The major sources of noise in digital images are imperfect instruments, interference natural phenomena, problem with data acquisition process, compression and transmission. Noise is present in image either in additive form or multiplicative form [1], [2]. Image denoising forms the preprocessing step in the field of photography, medical science, technology and research, where somehow image has been corrupted and wants to be restored before additional processing [3].

Over the past few decades, *fuzzy logic* has been used in a wide range of problem domains. Although the fuzzy logic is relatively childish theory, the areas of applications are very broad [4] . Fuzzy logic is a form of many-valued logic or probabilistic logic, it deals with approximate reasoning. It has been absolute to handle the concept of partial truth, where the truth value may range between completely true and completely false. In Fuzzy Image processing fuzzy set theory is applied to the task of image processing. Fuzzy Image Processing is depends upon association values, inference engine and rule-base. The uncertainty in image segmentation and subsequent extraction from noise affected scene successfully handled by Fuzzy Logic [5].

2. Fuzzy Sets And Fuzzy Logic

Fuzzy Logic is a means of dealing with information in the same way that humans of nature do. Fuzzy Logic is built around the concept of reasoning in degrees, rather than in Boolean (yes/no 0/1) terminology like computers do. Variables are defined in terms of fuzzy sets. Rules are specified by logically combining fuzzy sets. The combination of fuzzy sets defined for input and output variables, together with a set of fuzzy rules that relate one or more input fuzzy sets to an output fuzzy set, which built a fuzzy system. Fuzzy systems represent well-defined static deterministic functions Therefore reaction of a fuzzy system to inputs is anything but fuzzy. Inputs are presented to the system as specific values, and the fuzzy system produces a specific output value. The operation of a fuzzy system is thus analogous to that of conventional systems. Most of the fuzzy systems are for to use in decision making or pattern recognition applications. An ordinary set splits the data into those items that are completely in the set and those items that are completely outside of the set. To understand it easily it can be explained by assigning the value 1 to all those data which are members of the set and the value 0 to all data which are not members of the set. For ordinary sets, only these two values is called the characteristic function of the set. In the following Fig. 1, we can see one of the application areas of fuzzy sets and fuzzy logic as applied on image processing area in stepladder. . Fuzzy image processing is the collection of all approaches that understand, represent and process the images, their segments and features as fuzzy sets. The representation and processing depend on the selected fuzzy technique and the trouble to be solved.[7]

A. Linguistic Variables

Linguistic variables are used to express fuzzy rules, which facilitate the construct of rule-based fuzzy systems [6]. A linguistic variable can be defined as a variable whose values are words or sentences. For example a linguistic variable such as age may have a value such as young, very young, old, very old rather than 30, 36, 18 etc. However, the advantage of linguistic variables is that they can be changed via hedges (fuzzy unary operators) [4].

B. Fuzzy if-then Rules

Fuzzy logic operates on the basis of rules which are expressed in the form of If-Then rules, which are written as follow:

*I*f <fuzzy proposition> then <fuzzy proposition>

A fuzzy proposition can be an atomic or a compound sentence. For example:

"Sky is blue" is an *atomic* fuzzy proposition.

"Sky is gray and wind is strong" is a c*ompound* fuzzy proposition.

C. Fuzzy Image Processing

Fuzzy image processing is a form of information processing for which input and output both are images. It is a set of different fuzzy approaches which process the images, represent and understand, their segments and features as fuzzy sets. Fuzzy image processing is divided into three main stages: image fuzzification, modification of membership values, and image defuzzification (if necessary as in Fig. 1.

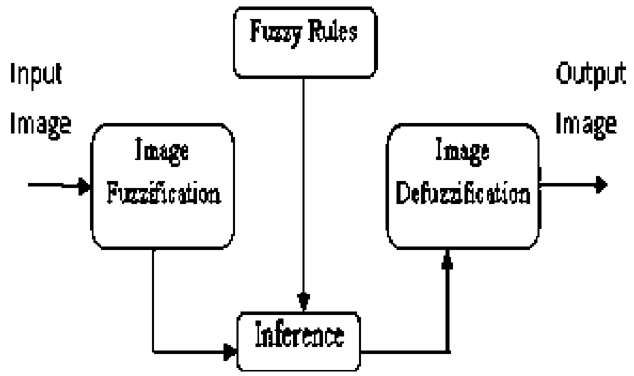

Fig. :1 fuzzy image processing

Due to the absence of fuzzy hardware we have to perform fuzzification and defuzzification steps. Therefore, we encode image data (fuzzification) and decode the results (defuzzification) to process images by means of fuzzy techniques. Power of fuzzy image processing lies in the intermediate step (modification of membership values) after first phase (image fuzzification), appropriate fuzzy techniques (such as fuzzy clustering, fuzzy rule-based approach, fuzzy integration approach and so on) modify the membership values [4].

D. FUZZY IMAGE ENHANCEMENT METHODS

Many kinds of fuzzy image enhancement methods have been proposed . For example:

• Fuzzy Contrast Adjustment
• Subjective Image Enhancement
• Fuzzy Image Segmentation
• Fuzzy Edge Detection
• Image enhancement

Most of these methods are based on image binarisation, while others enhance the image directly from gray-scale images. Gray-scale images enhancement approach include following steps :

(i) Normalization
(ii) local orientation estimation
(iii) local frequency estimation
(iv) Filtering by designed Filters.

In first step, an input image is normalized to decrease the dynamic range of the gray scale between ridges and valleys of the image estimation and the tuning of the filter parameters. Following are some of the methods used for enhancement of fingerprint images:

(i) Enhancement algorithm based on Image Normalization and Gabor filter .
(ii) Fourier domain filtering of fingerprint images.
(iii) Image enhancement using CNN Gabor-type Filters .
(iv) Enhancement of image using M-lattice.

3. FUZZY RULES

On the basis of following fuzzy rules, an image enhancement algorithm has been developed [6] and implemented:

- If pixel intensity is dark then output is darker.
- If pixel intensity is gray then output is gray.
- If pixel intensity is bright then output is brighter.

implementation of these rules in fuzzy inference system.

A. FUZZY LOGIC CLASSIFICATION

a) Matlab's Fuzzy Logic Toolbox

In the lack of precise mathematical model which will describe behaviour of the system, Fuzzy Logic Toolbox is a good "weapon" to solve the problem: it allows using *logic if-then rules* to describe the system's behaviour. This Toolbox is a compilation of functions built on the MATLAB® numeric computing environment and provides tools for creating and editing *fuzzy inference systems* within theframework of MATLAB. The toolbox provides three categories of tools:

- command line functions,
- graphical interactive tools and
- simulink blocks and examples.

The Fuzzy Logic Toolbox provides a number of interactive tools that allow accessing many of the functions through a graphical user interface (GUI). Fuzzy Logic Toolbox allows building the two types of system:

- Fuzzy Inference System (FIS) and
- Adaptive Neuro-Fuzzy Inference System (ANFIS).

b) Fuzzy inference system

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The process of
fuzzy inference involves: *membership functions*, *fuzzy logic operators* and *if-then rules.* There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox:

- Mamdani-type and
- Sugeno-type.

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology and it expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant. This fuzzy inference system was introduced in 1985 and also is called Takagi-Sugeno-Kang. Sugeno output membership functions (z, in the following equation) are either linear or constant. A typical rule in a Sugeno fuzzy model has the following form:

If Input 1 = x and Input 2 = y, then

Output is z = ax + by + c

For a zero-order Sugeno model, the output level *z* is a constant *(a=b =0).*

Membership function Membership function is the mathematical function which

defines the degree of an element's membership in a fuzzy set. The Fuzzy Logic Toolbox includes 11 built-in membership function types. These functions are built from several basic

functions:

- piecewise linear functions,
- the Gaussian distribution function,
- the sigmoid curve and
- quadratic and cubic polynomial curve.

Two membership functions are built on the *Gaussian* distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves . Membership functions built on the Gaussian distribution curve This type of membership function will be used later on, according to the results coming from PCI [3] .

The total variation is the integral of the absolute gradient of the signal [9]. Using TV regularization to remove noise from signals was originally proposed in and is based on the observation that noisy signals have high total variation.In this paper, we describe a different approach to define a directional TV. We also study a related denoising problem for discrete-space images and provide an algorithm for its solution.

The total variation (TV) of a discrete-space image f is defined as [10],

$$\mathrm{TV}(f) = \sum_{i,j} \sqrt{\left(\Delta_1 f(i,j)\right)^2 + \left(\Delta_2 f(i,j)\right)^2} \tag{1}$$

where Δ_1 and Δ_2 denote horizontal and vertical difference operators, (possibly) defined as,

$$\Delta_1 f(i,j) = f(i,j) - f(i-1,j) \tag{2}$$

$$\Delta_2 (i,j) = f(i,j) - f(i,j-1) \tag{3}$$

We can rewrite this as

$$\mathrm{TV}(f) = \sum_{i,j} \|\Delta f(i,j)\|_2 = \sum_{i,j} \sup_{t \in B_2} \langle \Delta f(i,j), t \rangle \tag{4}$$

where Δ is the linear operator defined as,

$$\Delta f(i,j) = \begin{pmatrix} \Delta_1 f(i,j) \\ \Delta_2 f(i,j) \end{pmatrix} \tag{5}$$

and B2 is the unit ball of the `2 norm. Henceforth, we use f to denote the matrix that represents the linear mapping defined in (5).

Total variation is isotropic because it is invariant under a rotation of the image (or, equivalently, the components of Δf). This is a consequence of the l_2 norm (or B_2) appearing in (4). We can obtain a directional total variation by replacing B_2 with some other set. In particular, if we use an ellipse, $E_{\alpha,\theta}$ oriented along the angle θ, with a unit length minor axis and a major axis of length α > 1, the resulting norm

$$\mathrm{TV}_{\alpha,\theta}(f) = \sum_{i,j} \sup_{t \in E_{\alpha,\theta}} \langle \Delta f(i,j), t \rangle \tag{6}$$

is more sensitive to variations along θ.

Given this new total variation, we would like to have algorithms that use this pseudo-norm as a regularizer. In this paper, we study the denoising problem,

$$f^* = \operatorname*{argmin}_f \frac{1}{2} \|y - f\|_2^2 + \lambda \mathrm{TV}_{\alpha,\theta}(f), \tag{7}$$

where y is the given noisy image. Specifically, we derive an algorithm that solves this problem and apply it to images to demonstrate its utility.

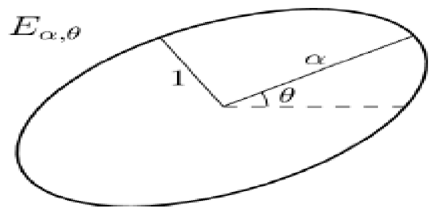

Fig.2. The ellipse $E_{\alpha,\theta}$ used to define the directional TV norm

by reducing the total variation of a noisy signal while keeping the resulting signal close to the original one removes noise while preserving important details such as sharp edges. Other existing denoising P techniques include median Filtering and Tikhonov-like regularization, kukTIK := i(rxu)2 i + (ryu)2 i . It is known that they tend to smooth away important texture details along with the noise. For a 2-D signal u 2 Rn_m, such as an image, the total variation kukTV of u can be defined anisotropically or isotropically: [8]

$$\|u\|_{TV} := \begin{cases} \sum_i |(\nabla_x u)_i| + |(\nabla_y u)_i|, & \text{(Anisotropic);} \\ \sum_i \sqrt{(\nabla_x u)_i^2 + (\nabla_y u)_i^2}, & \text{(Isotropic).} \end{cases} \tag{7}$$

4. Bv Space And Basic Properties

The space of functions with bounded variation (BV) is an ideal choice for minimizers to the ROF model since BV provides regularity of solutions but also allows sharp discontinuities (edges) [11]. Many other spaces like the Sobolev space *W*1;1 do not allow edges. Before defining the space BV, we formally state the definition of TV as:

$$\int_\Omega |\nabla f| = \sup \left\{ \int_\Omega f \nabla \cdot \mathrm{g} dx \mid \mathrm{g} \in C_c^1(\Omega, \mathbb{R}^n), |\mathrm{g}(x)| \leq 1 \forall\, x \in \Omega \right\} \tag{9}$$

where *f* 2 *L*1(-) and - *µ* R*n* is a bounded open set. For BV functions there is a useful coarea formulation linking the total variation to the level sets giving some insight into the behavior of the TV norm. Given a function © *f 2 BV* (-) and ° *2* R, denote by *ff* = °*g* the set:

$$\int_{\Omega} |\nabla f| = \int_{-\infty}^{\infty} \int_{\{f=\gamma\}} ds\ d\gamma. \qquad (10)$$

Here, the term $\int_{\{f=y\}}$ *ds* represents the length of the set $_{\{f=y\}}$. The formula states that the TV norm of *f* can be obtained by integrating along all contours of $_{\{f=y\}}$ for all values of *y*. Thus, one can view TV as controlling both the size of the jumps in an image and the geometry of the level sets.

A. Multi-channel TV

Total variation based models can be extended to vector valued images in various ways. An interesting generalization of TV denoising to vector valued images was proposed by Sapiro and Ringach . The idea is to think of the image u : $R^2 = R^m$ as a parametrized two dimensional surface in R^m, and to use the difference between eigen values of the first fundamental form as a measure of edge strength. A variational model results from integrating the square root of the magnitude of this difference as the regularization term.

B. Scale

The constant ¸ that appears in the ROF model plays the role of a \scale parameter". By tweaking ¸, a user can select the level of detail desired in the reconstructed image.

C. Caveats

While using TV-norm as regularization can reduce oscillations and regularize the geometry of level sets without penalizing discontinuities, it possesses some properties which may be undesirable under some circumstances.

a) *Loss of contrast.* The total variation of a function, defined on a bounded domain, is decreased if we re-scale it around its mean value in such a way

that the difference between the maximum and minimum value (contrast) is reduced .In this case, the contrast loss is in-versely proportional to *f*(*x*)=*r* before the disk merges with the background. In general, reduction of the contrast of a feature by $h > 0$ would induce a decrease in the regularization term of the ROF model by *O*(*h*) and an in-crease in the fidelity term by *O*(*h*2) only. Such scalings of the regularization

and fidelity terms favors the reduction of the contrast.

b) *Loss of geometry.* The co-area formula reveals that, in addition to loss of contrast, the TV of a function may be decreased by reducing the length of each level set. In some cases, such a property of the TV-norm may lead to distortion of the geometry of level sets when applying the ROF model their shape is preserved at least for a small change in the regularization parameter and their location is also preserved even they are corrupted by noise of moderate level.

D. *Variants*

Total variation based image reconstruction models have been extended in a variety of ways. Many of these are modifications of the original ROF functional, addressing the above mentioned caveats.

a) Iterated Refinement

A very interesting and innovative new perspective on the standard ROF model has been recently proposed by Osher et al. The new framework involved can be generalized to many convex reconstruction models (inverse problems) beyond TV based denoising.

b) Anisotropic TV

This can be useful in applications in which there may be prior geometric information available about 1. Recent Developments in Total Variation Image Restoration 9 the shapes expected in the recovered image. In particular, it can be used to restore characteristic functions of convex regions having desired shapes.

E. Total variation

Total variation (TV) penalizes abrupt changes in images. It is a very effective signal prior for piecewise smooth images as in Fig. 3 However, TV is an isotropic functional and is not very suitable for images with a dominant direction, like the one in [8].

(a) (b)

Fig.3 Total variation is a simple and effective prior for piecewise smooth images as in (a). We describe a directional total variation for images with a dominant direction as in (b).

For such images, one could, in principle, scale the image in order to reduce the dominance of the direction. However, for discrete-space images, scaling requires interpolation and therefore it is not very feasible. .

5. IMAGE QUALITY MEASUERMENT

In this section we discuss different image quality assessment techniques [10]. . We also present results of quality assessment performed using various objective metrics, namely, signal to noise ratio (SNR), mean square error (MSE), peak signal to noise ratio (PSNR) of best m-term estimate:

$$PSNR = 20\log_{10}(\max(f(x)) - \min(f(x))/(\|f - fm\|^2)\ (dB) \qquad (12)$$

where fm is the partial rebuild of f using the m biggest coefficients in magnitude, in the curvelet expansion [12].

MSE is Mean Square Error, and it is defined as follows:

$$MSE = \frac{1}{m*n}\left\{\sum_{i=1}^{m}\sum_{j=1}^{n}|\mathrm{Io} - \mathrm{Ip}|^2\right\} \qquad (13)$$

Where, the functions Io and Ip are original and denoised image, respectively. The number m and n are the size of an image [13].

6. CONCLUSION

In this paper, research work is basically concentrated on image denoising. Image denoising is the process of replacing or modifying the corrupted pixel value of the entire image based on the selected concept. In recent years researchers have invented many algorithms which are considerably efficient in removing noise present in the images. As per literature survey, in past most of the work done was only for noise removal, but most of the time it was found that, due to image denoising process the images are highly blurred. We described a modification to the standard DTV so as to make it image denoising problem in all direction. The main advantage of this paper use Fuzzy logic function to help to minimize impulsive noise in all Direction. We verified that for images with Directional TV, The Fuzzified directional TV is a more suitable prior than standard DTV. We also discussed the special effects of the parameters in the introduced directional Fuzzified DTV.

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