Applied Intelligence for Medical Image Analysis

Aarti | Raju Pal | Mukesh Saraswat | Himanshu Mittal
Editors

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Abbreviations

ADBIS	adaptive decision-based interpolation scheme
ADPM	anisotropic diffusion of Perona and Malik
AF	adaptive filters
AMF	adaptive mean filter
ANN	artificial neural networks
ASH	American Society of Hematology
BN	batch normalization
CDR	cup-to-disc ratio
CF	cascaded filters
CNN	convolutional neural network
DBF	decision-based filters
DL	deep learning
DLSFINR	denoising SAP noise in color images
DNN	deep neural network
DPAD	detail preserving anisotropic diffusion
DR	diabetic retinopathy
DT	decision tree
FLND	fuzzy logic noise detector
FSBMMF	fast switching-based mean median filter
HF	hybrid filter
HVS	human visual system
IBINR	interpolation-based impulse noise removal
IR	infrared
IRT	infrared thermography
ITC	infrared thermographic calorimetry
KNN	*K*-nearest neighbors
LR	logistic regression
LSTM	long short-term memory
MAC	malignancy-associated changes
MAE	mean absolute error
MAPE	mean absolute percentage error
MDBUTMF	modified decision-based unsymmetric trimmed median filter
MI	mutual information

MLP	multilayer perceptron
MRI	magnetic resonance imaging
MSE	mean square error
NB	naive Bayes
ND	noise densities
NEC	necrotizing enterocolitis
NICU	neonatal intensive care unit
OD	optical disc
PCOS	polycystic ovary syndrome
PSNR	peak signal-to-noise ratio
PSO	particle swarm optimization
ReLU	rectified linear unit
RF	random forest
RMSE	root-mean-square error
RMSLE	root-mean-square-logarithmic error
RNN	recurrent neural networks
ROI	region of interest
RR	respiration rate
SAP	salt-and-pepper
SF	switching filter
SRAD	speckle reducing anisotropic diffusion
SSIM	structure similarity metrics
SVM	support vector machine
VCDR	vertical cup-to-disc ratio
VLSI	very large-scale integration
WBCs	white blood cells
WOA	whale optimization algorithm
XGB	extreme gradient boosting

Preface

This book serves as a platform for academia, researchers, and industrial technocrats working in the medical field and related domains to contribute both theoretical and practical evaluations in research pertaining to the design and implementation of secure and sustainable computing and communication technology for the medical field. The applications are listed below:

- Security and integrity solutions for the medical field.
- Energy efficient computing algorithms for medical imaging.
- Machine learning and deep learning techniques for the medical field.
- Image processing methods for improving medical image quality.
- Analysis of radiomics.

Fundamental concepts of applied intelligence for medical image analysis are illustrated in a clear and detailed manner, with explanatory diagrams wherever necessary. All the chapters are organized and described in a simple manner to facilitate readability.

CHAPTER ORGANIZATION

Every chapter is supported by technological concepts and an illustrative analysis and solution to enlighten the readers.

This book introduces novel models to address sustainable solutions for issues related to medical image analysis.

It offers perspectives for design, development, and commissioning of intelligent applications.

It also puts forward some insights into sustainable and intelligent medical imaging techniques for the future generation.

Medical imaging includes ultrasound, computing tomography, magnetic resonance imaging, microscopy images. Medical imaging is considered as a resource for research in the medical field for scientists and engineers, clinicians, undergraduate, and graduate students.

Chapter 1 discusses the comparative study of anisotropic diffusion filters for medical image denoising.

Chapter 2 provides an extensive survey on the state-of-the-art impulsive noise removal techniques for noise medical images like MRIs, X-rays, etc.

Chapter 3 presents a comparative analysis between segmentation based on particle swarm optimization and whale optimization algorithm for brain tumor detection.

Chapter 4 discusses breast cancer screening using fractal dimension of chromatin in interphase nuclei of buccal epithelium.

Chapter 5 discusses the polycystic ovary syndrome classification based on machine learning techniques.

Chapter 6 provides a detailed review on Alzheimer's disease diagnosis methods using ensemble methods and machine learning.

Chapter 7 discusses the new strategy for the prediction of diabetic retinopathy using deep learning methods and firebase technology and discusses contactless monitoring in newborns using infrared thermography. This chapter describes and explains infrared thermography used in the monitoring of vital physiological parameters during the neonatal period.

Chapter 8 presents an analysis of medical images using machine learning techniques.

Chapter 9 provides a comparative analysis of retinal disease diagnosis using machine learning techniques.

Chapter 10 discusses a new method for automated segregation of lymphoid and myeloid blasts in acute leukemia using deep learning.

Chapter 11 evaluates four deep learning architectures (LSTM, stacked LSTM, CNN-LSTM, Encoder-Decoder LSTM) for predicting patient drug expenditures.

Chapter 12 focuses on COVID-19 diagnosis. This chapter explores classifying chest X-ray images using various classifiers, with a custom artificial neural network (ANN), achieving 95.5% accuracy.

Chapter 13 uses a deep learning approach with AlexNet. This chapter automatically categorizes cardiac arrhythmia via ECG signals, achieving over 99% accuracy, surpassing traditional methods.

Chapter 14 presents a CNN-based approach to classify mammogram images as normal, benign, or malignant, obtaining a high accuracy rate of 96.4% across multiple views, enhancing breast cancer diagnosis.

Acknowledgment

I would like to thank the colleagues of the Department of Computer Science and Engineering at the Lovely Professional University and Jaypee Institute of Information Technology for their support during the writing and maintaining of this book.

Introduction

With the advancement in technology and increased innovation over the past several decades, there has been a revolution in the analysis of medical images. Software automation has given birth to vivid intelligent technologies that can analyze and interpret medical images without human intervention. For instance, the performance demonstrated by deep learning techniques in the identification of illnesses is impressive. Additionally, the accessibility to a vast array of medical images and other forms of medical data has benefited the use of intelligence to create tailored tools for disease evaluation and suppression of emerging diseases.

Machine learning has proven to be widely accepted as one of the most powerful tools for conducting research in this domain. The platform not only uses the benchmark dataset, but also applies a certain level of intelligence for analyzing and thereby reaching a conclusion in the form of a result. This book *Applied Intelligence for Medical Image Analysis* provides free access to this reasoning and framework-building research.

SALIENT FEATURES

The scope of *Applied Intelligence for Medical Image Analysis* encompases the use of intelligent systems in industry, medical, and daily life:

- Covers the application of deep learning techniques for medical image problems.
- Covers the development of future machine learning techniques and further application of existing techniques.
- Contains chapters with literature reviews using deep learning methods for medical image analysis.
- Covers the applications of medical image applications including the diagnosis of medical images, image genomics, and brain connectomics.
- Covers the latest technologies and algorithms related to the state-of-the-art medical image analysis in assessing and diagnosing diseases.

CHAPTER 1

A Comparative Study of Anisotropic Diffusion Filters for Medical Image Denoising

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ABSTRACT

Noise is an important factor that can reduce the image quality and its appearance. Therefore, it must be removed while preserving the texture and the characteristics of the original image. Images can be corrupted by different types of noises and the choice of the filter depends on the use of the image and its application. In fact, selecting the appropriate denoising algorithm is closely related to the kind of noise in the image. This chapter aims to present different types of filtering algorithms based on anisotropic diffusion and applied to different types of medical images to obtain the best denoising approach. At the end, a comparative study is done using quantitative and qualitative performance evaluations.

1.1 INTRODUCTION

The most important digital image processing technique is image enhancement, which refers to the description and refinement of image

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characteristics such as edges or contrast so that the graphical displayed become more useful for analysis.[26,27] The image improvement is achieved using a set of techniques that seek to improve the visual appearance of an image or transform the image into a more suitable shape to be analyzed by a human or a machine. Image enhancement includes grayscale manipulations and contrast leveling, noise reduction, contour sharpening, filtering, interpolation, and amplification.[20]

Noise is an important factor that leads to a significant reduction in the quality of the image or video. This signal appears automatically in an image during the process of acquisition and transmission. In fact, noise is usually generated by electronic components in medical instrumentation; it is a random signal that is still present in many medical data, even if the electronic designs try to minimize it.[14] It may come from a source part of the image capture devices, the memory location may be defective or it may be induced due to the conditions of the capture devices such as cameras, misaligned lenses, diffusion, and other adverse conditions that may be present in the atmosphere. Its identification with eyes is very difficult so that processing algorithms are necessary for a satisfactory extraction of the useful characteristics of the images. Regardless of the type and characteristics of the noise, it is an undesirable content in the image. All medical images contain obviously some proportion of visual noise.[10] This signal gives the image a granular, snowy, or textured appearance, and it hides some information which can make diagnosis difficult for a doctor. Fundamental types of noise such as Gaussian noise, salt and pepper, speckle, and many others can be found in digital images.[9] A careful study on the different types of filters is needed to select the appropriate noise to reduce it as much as possible. Image filtering is therefore a preprocessing step essential and indispensable for many applications such as image compression, segmentation, identification, merging, object recognition, and so on.[4,22,23] The appropriate filter is chosen depending on the image characteristics, which is also related to its modality. Different linear and nonlinear filtering methods have been developed depending on the noise power or the applications for which the image is intended; each filter has different mathematical or empirical bases. Various examples of noise removal techniques have been used in medical imaging: for the study of anatomical structure and the processing of MRI, ultrasound, X-ray scanner, and endoscopy images. In the field of digital image processing, linear filtering has long been a major focus; they are easy to implement and inexpensive to calculate but not well suited to "real" images obtained from physical sensors. Indeed, most of these sensors are essentially nonlinear.

This is particularly true of the human visual system (HVS). These filters are therefore unable, for example, to eliminate impulsive noise without blurring the contours. In addition, the fast increase in the power of computing systems has made the computational complexity argument largely obsolete. This is why the development of nonlinear image processing methods has been observed. Nonlinear filtering methods are very diverse. The choice of the most efficient method for medical image denoising is very complex. It depends especially on the modality and characteristics of the image. In this work, we will establish a comprehensive study of anisotropic diffusion-filtering methods. We will test each of the filtering techniques on ultrasound, IRM, CT scan, and endoscopy images; for that, we will use in the first experiment a Gaussian noise and in the second a speckle noise. We will evaluate each algorithm and establish which filtering technique is the most appropriate for each tested medical image mode. This kind of study for such different types of medical images is very limited in the literature[21] and the comparison study in this work has proven again the complexity of the nonlinear filtering of medical images.

This chapter is organized as follows: Section 1.2 presented a qualitative study of anisotropic diffusion methods. In Section 1.3, results and discussions is given. And finally, we conclude our work.

1.2 THE NONLINEAR ANISOTROPIC DIFFUSION TECHNIQUES

The use of nonlinear filtering techniques is already important in image processing applications; it gives better results than linear filtering, removing the noise without changing the image characteristics.[6,17] However, the design and the computational implementation of the nonlinear filters are more complex. These techniques modify each pixel's value on the image according to the returned value by a nonlinear function depending on the neighboring pixels. These filters are mainly used for noise elimination and edge detection.[15] The most well-known traditional function is the median filter.[24]

There is also the wavelet transformation, which is a method of nonlinear transformation; it has a good localization property and became an important tool for image filtering.[16] In literature, several works have been devoted to the anisotropic diffusion.[1–3] With the development of graphic processor and hardware platform, various implementations of those nonlinear filters have been proposed.[8,11–13] Thus, the choice of filter depends fundamentally on the image type, the noise type, and the domain of use of the image.

1.2.1 PERONA AND MALIK FILTER

Linear spatial filtering, such as the Gaussian filtering, computes the value of a pixel by merging the weighted average values of its closest neighbors. This filtering can reduce the noise amplitude variations, but it also masks details such as lines or contours, so that the resulting images appear blurry and degraded. Perona and Malik[25] developed a method based on anisotropic diffusion called anisotropic diffusion of Perona and Malik (ADPM), a multiscale edge detection and smoothing system, which is a powerful concept in image processing. The heat diffusion equation inspired the anisotropic diffusion by introducing a diffusion function "*g*," that depends on the image gradient.

$$\partial u / \partial t = div\ (g\ (|\nabla u|)\nabla u) \tag{1.1}$$

where ∇ and u denotes, respectively, the gradient operator and the intensity of the image, *div* is the divergence operator, and |.| denotes the magnitude. In addition, the variable t is used to list the steps of the iterations in the discrete implementation.

1.2.2 SRAD FILTER

In the work of Yu,[28] a simplified version of Lee's filter was compared with the anisotropic diffusion filter proposed by Perona and Malik, which led to a modified anisotropic diffusion technique that they called speckle reducing anisotropic diffusion (SRAD);[28] it can be written as follows:

$$u_{i,j}^{t+\Delta t} = u_{i,j}^{t} + \frac{\Delta t}{\eta_{i,j}} div\left[c_1\left(q_{i,j}^{t}\right)\nabla u_{i,j}^{t}\right] \tag{1.2}$$

where Δt is the iteration step, c1(...) is the diffusion function given by

$$c_1(q) = \frac{1}{1+\frac{\left[q^2(x,y;t)-q_n^2(t)\right]}{\left[q_n^2(t)\left(1+q_n^2(t)\right)\right]}} \tag{1.3}$$

and $q(x,y;t)$ is the instantaneous CV, which allows separating homogeneous regions from edges in bright and dark areas; it can be considered as a discretization of

$$q = \sqrt{\frac{\frac{1}{2}\left(\frac{|\nabla u|}{u}\right)^2 - \frac{1}{16}\left(\frac{\nabla^2 u}{u}\right)^2}{\left[1+\frac{1}{4}\left(\frac{\nabla^2 u}{u}\right)\right]^2}} \tag{1.4}$$

Here, $q_{n(t)=C_n^2}$ is the speckle scale function. In the presence of speckle noise; both the SRAD with the CV play a very important role in edge detection. To compute C_n^2, the SRAD needs to identify a homogeneous region within the processed image.

1.2.3 DPAD FILTER

In 1985, Kuan proposed a denoising method for multiplicative noise without using the linear model made by Lee.[19] The filter can be written very similar to Lee's:

$$\hat{u} = \underline{u} + k_2\left(u - \underline{u}\right) \tag{1.5}$$

with

$$k_2 = 1 - \frac{1+\frac{1}{C_u^2}}{1+\frac{1}{C_n^2}} \tag{1.6}$$

As mentioned above, the filter proposed by Lee is the origin and the bone of the SRAD filter.

Similar to the SRAD filter technique, Aja-Fernandez[5] has developed another anisotropic diffusion filter by merging the anisotropic diffusion with Kaun's filter rather than Lee's filter. It was named "detail preserving anisotropic diffusion" (DPAD).

The method has better performance detecting image details and reducing noise. Equation 5 can be written as

$$\hat{u} = u + \left(1 - k_2\right)\left(\underline{u} - u\right). \tag{1.7}$$

Following a similar approach to that in the section above, and if we call $(C_2 = (C_u(x,t) = (1 - k_2)$, the expression of the DPAD filter can be written as follows:

$$u_{i,j}^{t+\Delta t} = u_{i,j}^{t} + \frac{\Delta t}{\eta_{i,j}} div\left[C_2\left(C_u\left(i,j;t\right)\right)\nabla u_{i,j}^{t}\right] \tag{1.8}$$

1.2.4 OSRAD FILTER

Until now, the anisotropic diffusion definition is closely related with scattering which is a scalar function changing with the location in the image. As discussed above, the Perona and Malik diffusion limit the image smoothing near the pixels with a high-gradient amplitude (edge pixels). Near an edge, the diffusion is very low, so the noise smoothing near the edge is also low. To solve this problem, diffusion functions using matrix instead of scalars have been proposed, where anisotropic diffusion allows different diffusions in separate directions related to the local geometry of the image structures. Thus, both sides diffusion of an edge can be avoided, and in the same time, diffusion along the edge can be allowed. As a result, the edge will not be smoothed neither removed during the filtering process. Let F be the flow of the diffusion matrix which is written as follows:

$$F = div(D\nabla u) \tag{1.9}$$

where D is a positive-defined symmetric matrix adapted to the image local structure, which can be written in terms of its eigenvectors v_1 and v_2 and its eigenvalues λ_1 and λ_2 as follows:

$$D = \left(v_1 \quad v_2\right)\left(\lambda_1\, 0\, 0\, \lambda_2\right)\left(v_1^T\, v_2^T\right) \tag{1.10}$$

and the gradient vector is written as

$$\nabla u = u_{v1}.v_1 + u_{v2}.v_2. \tag{1.11}$$

In his work, Karl,[18] used a 2D base (v_1^*, v_2^*) which corresponds, respectively, to unit vectors in the gradient directions and to the minimum curvature of the smoothed version of the image, obtained convoluting the image in question with a Gaussian filter with a standard deviation σ.

This base is particularly interesting in the context of very small structures in the human body such as blood vessels, where the direction of the orthogonal axis to the gradient is held by the minimum curvature. These directions are obtained as two eigenvectors of the Hessian matrix of the smoothed image H_σ. Therefore, eigenvectors are defined as follows:

$$v_1^* \parallel \nabla_{u_\sigma} \tag{1.12}$$

$$v_2^* \perp \nabla_{u_\sigma} \tag{1.13}$$

where ∇_{u_σ} is the gradient of the image convoluted by a Gaussian filter with a standard deviation of σ, v_2^* gives an approximation on the direction of the vessels, and v_1^* its orthogonal. In addition, the diffusion function used by Karl is based on the eigenvalues of Eq. 10, it is associated with each vector of the base combining the first-order derivative of intensity in that direction. This method replaces the traditional norm of the smoothed gradient. In addition, the diffusion can be decomposed in each direction of the orthogonal base as a sum of diffusions and the divergence operator can be explicitly written as

$$div(F) = div\left(\sum_{i=0}^{2} \varphi_i\left(u_{v_i}^*\right).\ v_i^*\right) = \sum_{i=0}^{2} div\left(\varphi_i\left(u_{v_i}^*\right).\ v_i^*\right) \tag{1.14}$$

where u_{vi}^* and φ_i indicate the first-order derivative of intensity in the v_i direction and the ith diffusion function, respectively. In addition, φ_i is chosen as one of the diffusivity functions of the traditional nonhomogeneous isotropic diffusion equation, which is dependent on the intensity first-order derivative in that direction, such as $\varphi_1\left(u_{v_1}^*\right) = u_{v_1}^* e^{-\left(\frac{u_{v_1}^*}{k}\right)^2}$ and $\varphi_2\left(u_{v_2}^*\right) = \alpha \cdot u_{v_2}^*$ with $0 < \alpha < 1$ being only a diffusion function to allow smoothing in the v_2^* direction.

1.3 RESULTS AND DISCUSSIONS

1.3.1 IMAGES CORRUPTED WITH GAUSSIAN NOISE

In medical imaging, techniques aiming to noise removal have become an essential practice for the study of various anatomical structures and the processing of MRI, ultrasound, X-ray scanner, and endoscopy images. Depending on the characteristics of the image, which also depends on its modality, the appropriate filter is chosen. The following are performed and verified with MATLAB, using a PC equipped with an Intel(R) Core (TM) i7-4510U CPU 2.60 GHz.