A novel anisotropic diffusion approach for teaching image enhancement technology

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ABSTRACT: The techniques and technology for *denoising* printed text characters from scanned historical documents forms a defined part of the content in information technology education. In this article, a class teaching case is reported based on designing three visual experiments involving image enhancement. It is pointed out to undergraduate students that the traditional anisotropic diffusion equation method is not suitable for the image enhancement of blurred printed text. New convolution masks are subsequently put forward as part of a novel anisotropic diffusion equation, in order to improve the enhancement. Course experiments verify that the novel method can more efficiently recover the text strokes from background grey noise, with less computational time. Such algorithm design is important for image enhancement education, and the visualised class teaching can effectively attract the students' attention.

INTRODUCTION

Paper-printed manuscripts have been scanned into binary codes, making them easier to process, transmit, and display. The automatic recognition of printed text characters from the scanned documents is important in information processing. But, when it comes to historical papers, such factors as ink-blur, paper-aging and dye discolouration of the coatings have reduced recognition accuracy. As a result, denoising procedures for the digitised images is an important component of the information processing technology that supports these operations and, hence, is important for undergraduate students who are studying in this area. Text image analysis is normally applied to two-dimensional (2D) documents scanned when flattened against a planar surface.

A course about the image enhancement of scanned documents is proposed in this article. To manipulate the 2D binary array, which is mapped from the image, the course teaching is aimed at studying the denoising of text images. There is an introduction to the *ordinary* anisotropic diffusion equation method of image enhancement and its use. Following this, a novel modified algorithm is developed and tested. Finally, the novel method is applied to non-textural material. Conclusions are then drawn. The course is designed around visual experiments, and a restricted time is required to cover the material.

LITERATURE SEARCH

The processing of scanned documents or in other words the digitalised hardcopy images, has drawn more and more attention from academic circles and from industry. Pilu et al described an image processing *pipeline* used to enhance text image capture and fast text extraction, which could be integrated into a hand-held low-resolution camera [1]. Kawano et al filed a patent, which describes an image processing apparatus to perform colour conversion on an input image, such as a scanned image [2]. Alata et al reported fuzzy image processing methods to encode the image and find the characters in the image [3]; the characters could be Verdana, Arial or Lucida Console. Yin et al researched handwritten Chinese text based on minimal spanning tree (MST) clustering with a distance metric, in order to separate text lines in unconstrained handwritten documents [4].

Wu et al proposed an approach using the texture of a document image to infer the document structural distortion in order to correct the image. Wu opined that …*the proposed approach may handle document images that include multiple fonts, math notation, and graphics* [5]. He et al presented a method based on a hidden Markov tree (HMT) model for off-line, text-independent identification of handwritten documents [6]. To precisely segment text characters in images and videos, Yang et al proposed a method to adaptively find the horizontal and vertical cutting positions, with a shortest-path searching method to remove noise in the text characters [7]. In applying a wavelet algorithm to denoise text images, Fu et al reported that a multi-scale wavelet could handle …*the character image by extracting wavelet energy density features and applying a BP back propagation neural network to classify the different fonts* [8].

BACKGROUND TO ANISOTROPIC DIFFUSION PDE

With white-and-black text images, there appear sudden changes between the text strokes and the noisy background, and the noise superposed on the strokes can only be neglected to a degree. The partial differential equations (PDE) technique is an effective way to discriminate such kind of noise [9]. However, there are few reports of dealing with printed text images by PDE.

In order to apply the PDE method for printed text denoising in the image enhancement course, the author proposes a PDE model of anisotropic diffusion be used in a teaching case. The case is established on the basis that the essential geometry of printed text strokes contains a regular framework structure to be discriminated from the background noise.

The defects of the ordinary diffusion equation are visually explained to the students and a new, nonlinear directional diffusion PDE is outlined. The proposed PDE performs an anisotropic diffusion in orthogonal directions for preserving the strokes' edges during the denoising process.

IMAGE DENOISING BASED ON ANISOTROPIC DIFFUSION PDE

Diffusion Equation

The diffusion equation is deduced from the *Gaussian* filter for multi-scale image analysis. Since isotropic diffusion defines a linear, space-invariant transformation of the original image and the noise reduction near the image edge is poor, anisotropic diffusion is proposed to allow the diffusion to be different in different directions.

The anisotropic form of the diffusion equation [10] is written as:

$$\frac{\partial}{\partial t} I(x, y, t) = \nabla \cdot (D(x, y, t) \nabla I(x, y, t)) \tag{1}$$

In Equation (1), $D(x, y, t)$ is the diffusivity, '∇ or grad', and $\nabla\cdot$ *or div* are the usual gradient and divergence operators respectively. $I(x, y, t)$ is the time varying 2D image $I(x, y)$, with initial conditions $I(x, y, 0) = I_0(x, y)$; I_0 is the original image before the denoising process.

The anisotropic diffusion equation can be solved numerically using the finite difference method. The spatial derivatives are approximated by central differences, and the temporal derivative is obtained by the forward difference approximation. The finite-difference equation is deduced from Equation (1), as follows:

$$\frac{I(k+1) - I(k)}{\Delta t} = A(I(K)) I(K) \tag{2}$$

In Equation (2), $I(k)$ defines the image at time step k. $A(I(k))I(k)$ is a discretisation of $\nabla\cdot(D\nabla I)$, which is essentially a convolution of the image with a mask, with weight element varying both spatially and temporally. Such spatial discretisation is usually applied to 3×3 masks. It is widely recognised that *anisotropic diffusion is a non-linear and space-variant transformation of the original image.*

Diffusion Masks

The 3×3 masks referred to above are fundamental for diffusive image processing. In this part of the course, ordinary diffusion masks in different directions are defined and presented in Table 1.

Table 1: Ordinary 3×3 masks for anisotropic diffusion in nine directions.

Ordinary masks in 3×3 format			
$\begin{bmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

The masks are two-dimensionally convoluted, with the original image forming the differential equation solution to integrate the image at a time step. Through iterations, the final solution is achieved, step by step. Such convolutions are realised using a Matlab program.

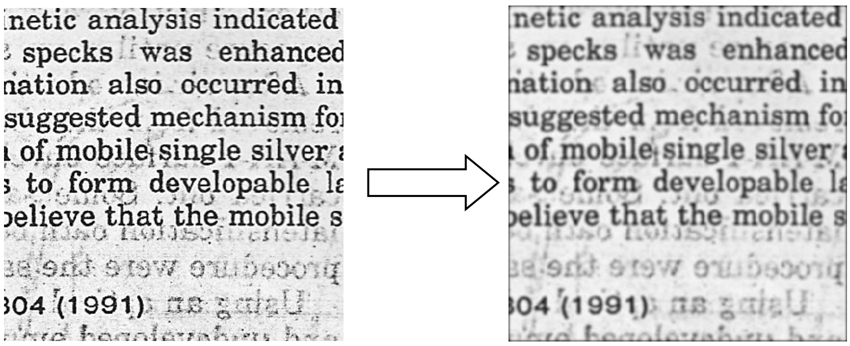
EXPERIMENTS AND RESULTS

In the course experiments, the ordinary masks in Table 1 are first applied to denoise the scanned text image. Then, questions are proffered to find more effective anisotropic diffusion masks which, then, can be verified by image denoising experiment. A progressive set of experiments, thus, can be developed. A description of the experiments follows:

- Experiment 1: Denoising based on traditional diffusion masks:

  The 442×442 pixel image, shown in Figure 1a, was selected as the first visual example from a printed text image database. This database has been established for teaching by scanning various manuscripts. The original image is blurred by background noise, which appears as grey shadows between the text words. Such blurs originated from the scanning process caused by apparatus errors.

  The ordinary spatial discretisation masks in Table 1 were applied. Figure 1b shows that the quality of the text image versus background has deteriorated after four iterations; there has been a distortion of the strokes, as well as a deepening of the background grey noise. The contrast of the strokes' edges has been weakened by using such traditional anisotropic diffusion masks. The students, then, consider how to modify the masks to better recover printed text.



a) b)

Figure 1: a) Original scanned English text image; b) Image processed using the Table 1 masks.

- Experiment 2: Denoising based on modified diffusion masks:

  The strokes of text words have the characteristic that the pixel between two edges is continuous and the edges are a sharp contrast to the background. The template of the anisotropic diffusion equation should emphasise the middle element in the mask matrix, in order to increase the continuity of the strokes pixel. Also the surrounding pixels out on the edge should be decreased to 0 elements. Based on this analysis, the modified masks are presented in Table 2.

Table 2: Modified 3×3 masks for anisotropic diffusion in nine directions.

Modified masks in 3×3 format			
$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

  Compared with the masks in Table 1, the central elements in every 3×3 mask matrix in Table 2 have been enhanced, with the elements of value -1 in Table 1 changed to 1. Hence, the central image pixel would be preserved during denoising to enhance the image contrast between the strokes and the background.

  After the modified masks were applied through just one iteration, the denoising effect is shown in Figure 2. The background noise has been effectively decreased, and the contrast of the character strokes is improved. This verifies that the new masks have appropriately affected the strokes edges and central parts.

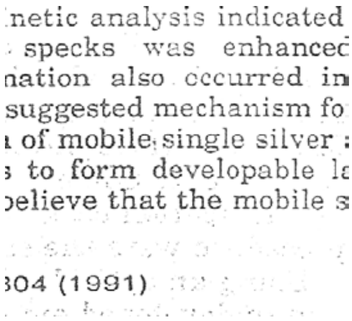


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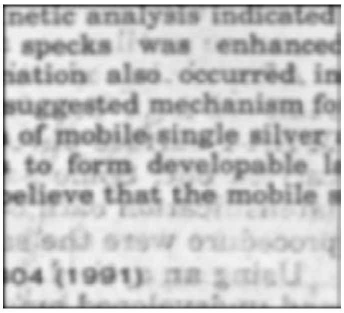
Figure 2: Image processed by the modified anisotropic diffusion masks of Table 2; one iteration.

The students' attention is drawn to the fact that the anisotropic diffusion PDE equation would have destroyed the strokes with more iterations. The strokes contrast becomes worse after 16 iterations using the ordinary masks as shown in Figure 3a; the strokes contrast in Figure 3b is badly deteriorated and seemed to be faded out after only two iterations using the modified masks. In Figure 3b, the border has been artificially outlined by broken lines to improve viewing.



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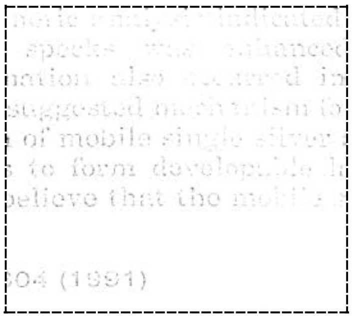

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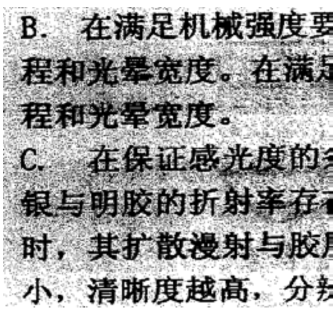
Figure 3: a) Ordinary masks; 16 iterations. Figure 3: b) Modified masks; two iterations.

The novel anisotropic diffusion method with modified masks is more sensitive in that a shorter time, i.e. fewer iterations, has achieved a higher denoising effect. As can be seen from Figure 3b), more iterations weaken the strokes, although the background noise is also depressed. Based on this experiment, the PDE with modified masks is verified to be fit for scanned blurring text image processing.

- Experiment 3: Further denoising:

Chinese Text

In technology education, it should be pointed out to students or audiences that many kinds of techniques are objective-oriented. Since though there are distinct differences between Latin alphabetic characters and Chinese pictographs, the modified PDE method defined above can be extended for Chinese text image enhancement. The original scanned Chinese text image chosen was blurred by grey background noise, as shown in Figure 4a. One iteration, using the modified masks in Table 2, produces the remarkable denoising effect, as seen in Figure 4b. The stroke structure of Chinese text is markedly sensitive to this novel anisotropic diffusion method.



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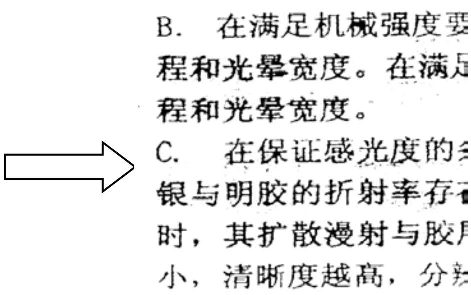

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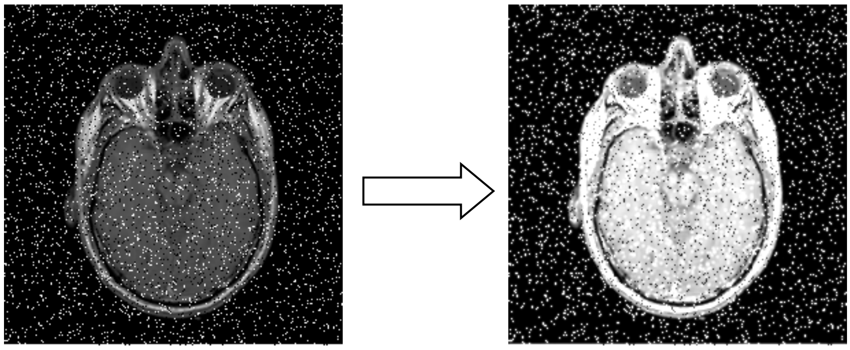
Figure 4: a) Original Chinese text image. Figure 4: b) Processed image using modified PDE; one iteration.

MRI Medical Images

An MRI image of a human head was selected for comparison. This has *salt and pepper* noise, as shown in Figure 5a. After one iteration, using the modified masks, there is some denoising effect, as shown in Figure 5b, although not as distinctive as the denoising of English and Chinese text images.



a) b)

Figure 5: a) Original MRI picture. Figure 5: b) Image processed using modified masks; one iteration.

Consequently, the final point, derived from the three examples in this teaching course case, is that the effectiveness of the proposed denoising PDE with modified masks is dependent on the specific kind of image, or, in other words, a general anisotropic diffusion PDE method will not be equally effective for all image enhancements.

NOTES ON THE TEACHING

During their sophomore year, students in the North China Electric Power University of China, are taught the course; all the figures and tables, as well as the basic theory are displayed using Microsoft PowerPoint to provide good visualisation. The difference between the character strokes of English (or Chinese) text and the background noise can easily be emphasised before and after the application of the ordinary and modified masks. To attract the attention of students, visual experiments are designed using Matlab software [11][12]. As discussed above, English text, Chinese text and brain MRI (magnetic resonance imaging) scans are processed as examples and displayed to the students.

All the content in this article can be presented in one lesson lasting 45 minutes, including the introducing of the background technique (5 min.), the basic image denoising method (10 min.), Experiment 1 (5 min.), modified anisotropic diffusion masks design (8 min.), questions and discussion, Experiment 2 (5 min.), Experiment 3 (5 min), and wrap up and conclusions (7 min.)

CONCLUSIONS

In this article, the theory and experiment components of an image enhancement course were described. Image enhancements of English text, Chinese text and MRI scans are given as examples for experiments in the course-teaching.

A novel anisotropic diffusion equation was established by modifying the 3×3 discretisation anisotropic diffusion PDE masks. The modified masks produced more effective denoising experimental results than did the ordinary masks. A conclusion is that although this novel method can be applied for denoising blurred text images, it is not effective or general enough to enhance other kinds of image.

Another conclusion is that the visualised experiments increase the students' enthusiasm on the image processing course. This can lead to more voluntary learning activity. Such audio-visual education methods should be further extended to other types of technology course at the University.

ACKNOWLEDGMENT

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