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Procedia Computer Science 00 (2019) 000–000

Procedia Computer Science

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4th International Conference on Computer Science and Computational Intelligence 2019 (ICCSCI), 12-13 September 2019

Enhancement of Indonesian license plate number image using shock filtering equation

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Abstract

Shock filtering equation is a mathematical model for enhancing image quality in partial differential equation form. In this paper, the equation is implemented to enhance the Indonesian vehicle registration number image. In this research the discretization of time and spatial domains use finite difference method which is a simple and straightforward approximation method. In this paper, several numerical simulations with different final time iteration are given. Here the results show that, the bluring image can be enhanced using shock filtering equation with long time simulation. Using subjective or visually approach, the image with 90-th iteration gives a good quality of visual image compared with the other final iterations. However, this result has lowest image quality metrics performance. The objective measurement shows that the best quality image is obtained at 10-th iteration, with discrete L^2-norm error 507.63, Pearson's correlation coefficient 0.961353 and PSNR 386.590 dB.

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Peer-review Statement: Peer-review under responsibility of the scientific committee of the 4th International Conference on Computer Science and Computational Intelligence 2019.

Keywords: Enhancement; shock filtering; image quality; image processing; finite difference method

1. Introduction

Image enhancement is one of the important techniques in image processing to investigate the information on image. Some raw images can be in low quality because of the presence of external and internal factors. For instance, the image from cctv footage has low quality of image such as blur, low intensity, ect [1], therefore increasing the quality of image is needed. In the classic problem, debluring image technique is required to help a system for recognizing vehicle registration number[2, 3, 4]. This technique is an important part to help system has high accuracy.

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This paper deals with the shock filtering equation [5, 6, 7] for each of pixels in an image as follows,

$$\frac{\partial I(x,y,t)}{\partial t} = -|\nabla I(x,y,t)| F\left(\Delta I(x,y,t)\right), \tag{1}$$

where $I(x, y, t)$ is the intensity of a pixel in a image at time t. The spatial variables x and y denote the location of pixel in two-dimensional domain. The function F is defined as a Lipschitz function. Moreover, ∇ and Δ are used to describe the gradient and Laplace operator respectively.

Here, the finite difference scheme (FDM) will be used to approximate the solution of (1) into image. Since this scheme is easy and straightforward to implement [8]. The discretization of FDM is derived from expansion of Taylor series. Recently, another method called Mac-Cormack's scheme is implemented in image processing [7]. However, this method is too complex but has second order accuracy of approximation in space and time. In this paper, the FDM for approximating (1) is in first order in time and second order in space. Here, shock filtering equation will be implemented to enhance the Indonesian vehicle registration number for simulation.

The next sections of this paper are organized as follow, in Section 2, the brief information of edge detection method and shock filtering equation will be given. In Section 3, the numerical FDM approach for discretizing the shock filtering equation is elaborated. The results and discussion are explained in Section 4. Finally the conclusion can be found in Section 5.

2. Edge Detection Method

2.1. Gradient approach

Edge in an image is the area where the intensity value of that area is changing significantly in a short distance. It also can be defined as the border of two different areas/colors in a image. Moreover, it can be oriented with the direction which depends on the changing of the value of intensity. For instance, see Fig. 1 for more detail about illustration of edge in an image.

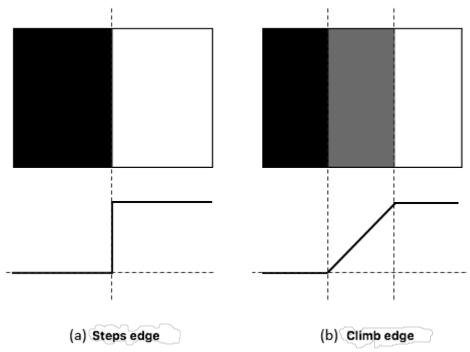


Fig. 1: The illustration of an edge from an image with different areas/colors.

In Fig. 1, there are two types of edge in an image. First type is called steps edge, where the different color of foreground and background is very contrast (see Fig. 1(a)). Meanwhile, in Fig. 1(b), second type of edge is called climb step, where the change of color is gradually in an image.

Edge detection in an image is a process with resulting edges pattern in an image. The goal of this process is to identify the parts of detail image. This process uses the significant change of the intensity value in the border of two different areas in image. Using the mathematical approach, partial differential equations (PDE), there are two ways (first and second order of PDE) to detect the edge. Some examples in first order of PDE type are called *Roberts*, *Prewitt*, and *Sobel* operator. In other hand, *Laplace* operator is a second order of PDE type.

In order to illustrate the operator, given $I(x, y)$ is the intensity of a pixel in image without considering the evolution of time. Here, (x, y) denotes the position of pixels in image which is described in domain $\mathbb{R}^2$.

- **First order operator**
  Mathematically, first order operator is given as following notation,

$$\nabla I(x,y) = \left(\frac{\partial I(x,y)}{\partial x}, \frac{\partial I(x,y)}{\partial y} \right). \tag{2}$$

- **Second order operator**
  Mathematical notation of second order operator is given as following equation,

$$\nabla^2 I(x,y) = \left(\frac{\partial^2 I(x,y)}{\partial x^2}, \frac{\partial^2 I(x,y)}{\partial y^2} \right). \tag{3}$$

  Generally, operator $\nabla^2 I(x, y)$ is denoted as $\Delta I(x, y)$ in some references.

First order operator (2) is enough to used for detecting either a pixel in the edge or not. Since by using this operator, if the gradient $I(x, y)$ is not zero, then the neighbors of $I(x, y)$ have different pixel value, thus pixel $I(x, y)$ is detected in an edge. However, this operator is difficult to detect if the pixel in the steps edge or not, since first derivative does not provide the zero crossing information.

Second order derivative produces the change of sign value in the derivative result. Thus, for detecting zero crossing easily, the idea using second order derivative (3) is come up. Therefore, the second order operator is an accurate operator to disclose the edge, specially the steps edge.

2.2. *Shock Filtering Equations*

Shock filtering is used to enhance the discontinue parts in image, which is can be called the edge of the image. In other hand, shock filtering is ignore the smooth parts in image. As explained in Section I Introduction, the shock filtering equation is given by (1). Note that, (1) is a hyperbolic partial differential equation type, which can be seen as a transport equation with a velocity function F. As introduced in [9], the function sgn can be used since this function satisfies

$$\begin{cases} F(0) = 0 \\ \operatorname{sgn}(z)F(z) > 0, z \neq 0 \end{cases} \tag{4}$$

where $\operatorname{sgn}(z) = 1$ if $z > 0$, $\operatorname{sgn}(z) = -1$ if $z < 0$, and otherwise $\operatorname{sgn}(z) = 0$ [6]. Thus the shock filtering (1) can be transformed into the following equation,

$$\frac{\partial I(x,y,t)}{\partial t} = -|\nabla I(x,y,t)| \operatorname{sgn}(\Delta I(x,y,t)), \tag{5}$$

$$I(x,y,0) = I^0(x,y), \tag{6}$$

where $I^0(x, y)$ describe the initial condition of image pixel.

3. Finite Difference Method for Shock Filtering Equation

Here, the focus is to discretized the shock filtering equation (5). Considering discrete domain Ω in two-dimension as follows,

- Let $i, j \in \mathcal{M} = \{1, 2, \cdots, N\}$, where $N > 0, \in \mathbb{Z}^{+}$. Thus, the pixel value at coordinate (i, j) can be denoted as $I(x_i, y_j)$. In this case the discrete space for spatial domain Δx and Δy is defined equal to one. Therefore, $x_i = \Delta x \times i = i$ and $y_j = \Delta y \times j = j$ are used for discretization of image. The illustration of $I(x_i, y_j)$ and other parts can be seen in Fig. 2.
- As shown in (5), the function I has three variables, two spatial variables and one time variable. Therefore, discrete time should be defined in this method. Giving $n \in \mathcal{T} = \{0, 1, 2, \cdots, T_n\}$ where $T_n > 0 \in \mathbb{Z}^{+}$, thus discrete time $t^n = \Delta t \times n$ with $\Delta t > 0$ is obtained.

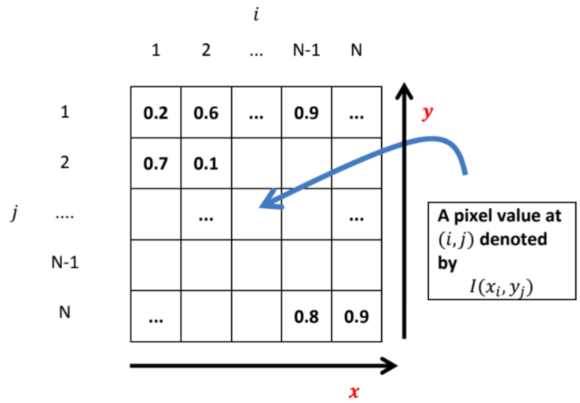


Fig. 2: The illustration of grid in discretization of image domain (size $N \times N$).

Finite difference method (FDM) is known as simple and straightforward method for approximating differential equation where the scheme is derived form Taylor series. Let's $I(x_i, y_j, t^n)$ is denoted by $I^n_{i,j}$, then the finite difference form of (5) is given as,

$$\frac{I^{n+1}_{i,j} - I^n_{i,j}}{\Delta t} = -\sqrt{\left(\frac{I^n_{i+1,j} - I^n_{i,j}}{\Delta x}\right)^2 + \left(\frac{I^n_{i,j+1} - I^n_{i,j}}{\Delta y}\right)^2} \times \operatorname{sgn}\left(\frac{I^n_{i+1,j} - 2I^n_{i,j} + I^n_{i-1,j}}{\Delta x^2} + \frac{I^n_{i,j+1} - 2I^n_{i,j} + I^n_{i,j-1}}{\Delta y^2}\right). \tag{7}$$

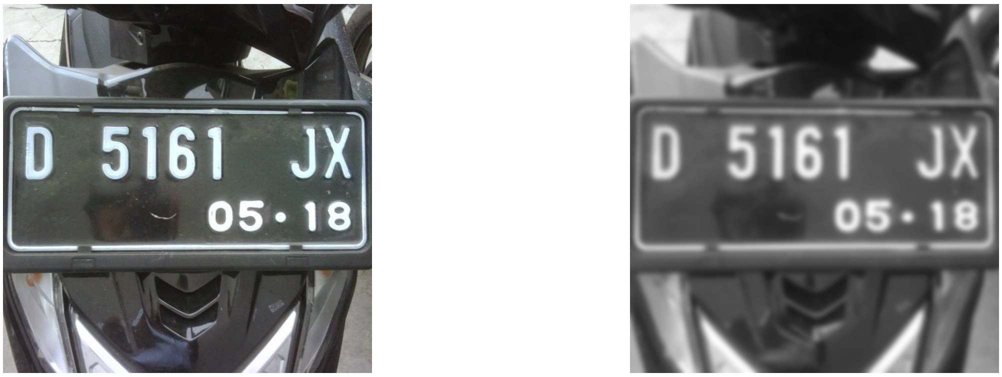
where function $\operatorname{sgn}(\cdot)$ is given as in (4). In order to conclude this numerical method then, the following algorithm (Algorithm 1) can be used in implementation.

Algorithm 1 FDM of shock filtering in image processing

Start
Input an image with size $N \times N$ as an initial condition $I^0_{i,j}$ for $i, j \in \mathcal{M}$
Define Δx, Δy, Δt, $n = 0$, T_n and $I^n_{i,j} = I^0_{i,j}$ for $i, j \in \mathcal{M}$
While $n < T_n$ **do**
    Solving (7) to obtain $I^{n+1}_{i,j}$ for $i, j \in \mathcal{M}$
    Updating $I^n_{i,j} = I^{n+1}_{i,j}$ for $i, j \in \mathcal{M}$ and $n = n + 1$
End

4. Results and discussion

In this section, the implementation of shock filtering equation (5)-(6) using finite difference method (7) (which concluded in Algorithm 1) is given. In this case one image of Indonesian license plate number will be used. The results of this implementation can be found in Fig. 3 and Fig. 4.



(a) Original image (b) Initial blur image

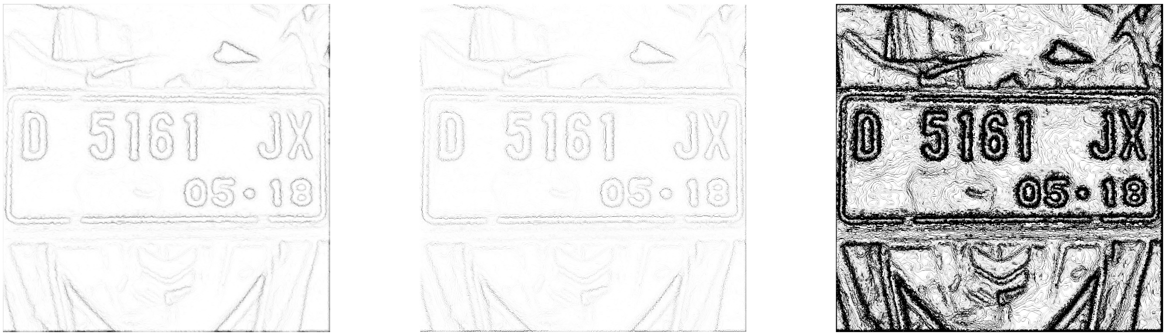
Fig. 3: The original image and blur image for initial condition.

(a) Result at 5 iterations (b) Result at 10 iterations (c) Result at 15 iterations

(d) Result at 30 iterations (e) Result at 60 iterations (f) Result at 90 iterations

Fig. 4: The enhancement results using shock filtering equation (5)-(6) with several iterations.

As shown in Fig. 3b, the initial image of this simulation is given in a blur image. This case is given since the goal of shock filtering equation is to enhance the image such that the image can be seen clearly as close as the original Fig. 3a. This technique also is called debluring technique [7]. Here, the results using discrete form of shock filtering (7) in 5, 10, 15, 30, 60 and 90 iterations can be found in Fig. 4a, Fig. 4b, Fig. 4c, Fig. 4d, Fig. 4e and Fig. 4f respectively.



(a) Edge detection using $|\nabla I|$ (b) Edge detection using ΔI (c) Edge detection using $-|\nabla I|\mathrm{sgn}(\Delta I)$

Fig. 5: The edge detection for enhancing image in 30-th iteration.

In order to analyze this results, let's see the edge detection process as shown in Fig. 5. This image is taken from 4d as an example. From (5), there are some parts in the right hand side of equation to describe the edge of the images. Indeed, they are first derivative $|\nabla I|$, second derivative ΔI and combination derivative in shock filtering $-|\nabla I|\ \mathrm{sgn}(\Delta I)$. Those derivatives are important parts for detecting the edge of the image thus the enhancement of image can be done. The results of edge detection for first, second and combination derivative can be seen in Fig. 5a, Fig. 5b and Fig. 5c respectively. Clearly from Fig. 5, using combination derivative in shock filtering image can produce a good quality image rather than only using first or second derivatives.

Visually, from the results in Figs. 4a - 4f, it can be seen that initial blur image is shown enhancing along the number of iterations. However this visual judgment is not enough to evaluate the sharpness enhancement of image since this is called subjective evaluation [10]. Therefore, to measure image quality objectively, the image quality metrics with two measurements are given in Table 1.

Table 1: The image quality metrics performance.

Measurement	5-th iteration	10-th iteration	15-th iteration	30-th iteration	60-th iteration	90-th iteration
$\|\|\{I_{i,j}\}\|\|_{L^2}$	13154.20	507.63	12971.17	14448.08	18273.39	20729.44
Pearson's correlation coefficient	0.960368	0.961353	0.960443	0.949545	0.920782	0.903590

As shown in Table 1, two measurements discrete L^2-norm error ($||\{I_{i,j}\}||_{L^2}$) [8] and Pearson's correlation coefficient [10] are used. Note that, in discrete L^2-norm error, the error is obtained form the discrepancy between original and final iteration image. In Table 1, the best quality image in sharpening enhancement is shown at 10-th iteration of simulation. Here, in 10-th iteration, smallest value of discrete L^2-norm error 507.63 is obtained and highest Pearson's correlation coefficient 0.961353 is observed.

Using long iteration is not guarantee that the quality of image is in a good condition. Comparing Fig. 4b and Fig. 4f visually, the quality of image in Fig. 4f which used 90 iterations is lower than Fig. 4b. Even the numbers of plate are shown clearly for both images, however some noises appear in image Fig. 4f. Indeed this results are confirmed in image quality metrics performance in Table 1. Here, Fig. 4f has lowest image quality where the error increasing $||\{I_{i,j}\}||_{L^2} = 20729.44$ and Pearson's correlation coefficient is decreasing 0.903590.

Furthermore, to provide an objective measurement for this simulation, the Peak Signal to Noise Ratio (PSNR) measurement is given in Fig. 6 for some iterations. According to Fig. 6, the PSNR is increasing from 1-st to 10-th iteration, otherwise the PSNR is shown decreasing which more than 10-th iteration. The highest PSNR is obtained at

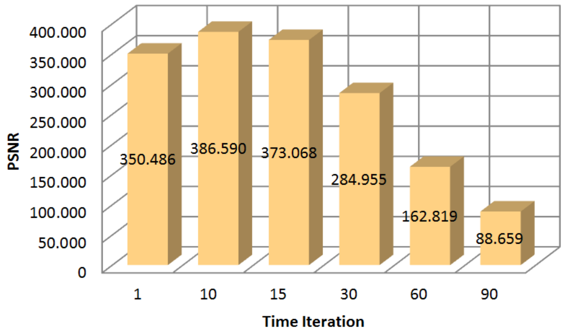


Fig. 6: The Peak Signal to Noise Ratio (PSNR) for each iterations

10-th iteration about 386.590 dB. However with high time iteration, the PSNR is shown very low. In this case PSNR is obtained 88.659 dB at 90-th iteration. The detail of PSNR for measuring image quality can be found in [11].

From three objective measurements in this paper, shock filtering equation (5)-(6) is observed able to enhance the blur image as close as to the original image. Similar to the results in [10], increasing the sharpness of image is not guarantee that the performance of image is also increasing. Unfortunately, this shock filtering equation has no optimization control for stopping criteria in time iteration. For further research this can be an open problem for any researchers to develop shock filtering equation engage with optimization control in time iteration.

5. Conclusion

Enhancing image using shock filtering equation is successfully implemented in Indonesian vehicle registration number image. In numerical simulation, the domain of image is discretized using finite difference method which is a simple method. The results of this simulation show that the image with 90-th iteration gives a good quality of visual image, however it produces lowest objective image quality metrics performance. Using three image quality measurements, result in 10-th iteration is observed as a best quality image in the simulation. Image in 10-th iteration has smallest value of discrete L^2-norm error 507.63, highest Pearson's correlation coefficient 0.961353 and highest PSNR 386.590 dB.

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