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Model-Based Design Methodology for Blind Image Restoration

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Abstract

Blind image restoration is a kind method of image processing by estimating both the original image and the point spread function from degraded images, when there is unknown or not completely know the prior knowledge of the original image and point spread function of imaging. However, blind image restoration is a complex and intensive computing process, and increasing processing speed has been a hot research topic. In this paper, blind image restoration using Self-Deconvolution Data Reconstruction Algorithm (SeDDaRA) is realized by Model-Based Design Methodology. The simulation results show that the proposed algorithm is not only simple in structure and easy to implement, and can improve the processing speed with good scalability.

Keywords: *Blind image restoration, SeDDaRA, Weiner filter, Model-Based Design*

1. Introduction

Image restoration [1] [2] is the image processing technology, which restores the real scene from the observed image based on the image degradation model. In the field of image restoration, the restoration of degraded images is often referred to as the classical image restoration when the point spread function (PSF) of the image degradation system is known. Classical restoration algorithms need to be known of the point spread function in advance, such as the inverse filter, Wiener filter, and improved fixed point image restoration algorithm However, in practical application, the point spread function of the image degradation system is often unknown, and the information of the degradation model can only be extracted from the degraded image in a certain way. This method is called blind image restoration, or image blind deconvolution.

Because blind image restoration [3-6] is a very complicated process, so it is a hot research topic to raise the speed of processing. With the development of information technology and microelectronics technology, the design of the system is becoming more and more complex. The method of traditional has been very difficult to meet the requirements of the current. However, the methodology of Model-Based Design (MBD) has many advantages, which provides the top-down design from algorithm to the hardware implementation for the user

The rest of this paper is structured as follows. Section 2 describes the basic principle of image degradation .The image degradation not only considers the factors of the system itself, but also considers the noise. Section 3 demonstrates the algorithm of image restoration by Wiener filter. Section 4 discusses the method for blind image restoration. The blind image restoration algorithm and its improved algorithm are discussed in detail in this section. Section 5 expounds the Implementation of blind image restoration by the methodology of MBD. In this section, we discuss the details of MBD methodology and the realization principle of blind image restoration using MBD. Finally, concluding remarks are drawn in Section 6.

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2. The Basic Principle of Image Degradation

Image restoration is a collection of techniques aiming at using a priori knowledge about the image degradation mathematical model [7]. It is attempted to find a model of image degradation and its parameters for a specific class of images provided by an application. Image restoration induces the solution of the inverse task to image degradation modeling. The linear model of image degradation is shown in Figure 1.

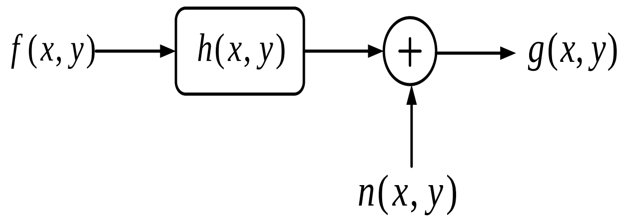


Figure 1. The Basic Model of Image Degradation

We assume that $f(x,y)$, $g(x,y)$ and $n(x,y)$ represent the input of image, output of image and noise respectively. A pair of images can be regarded as a series of point source. So $f(x,y)$ can be expressed by the convolution of the point-source function, and it is represented by

$$f(x,y)=\int\int_{-\infty}^{+\infty} f(\alpha,\beta)\delta(x-\alpha,y-\beta)d\alpha d\beta \quad (1)$$

Where δ represents point-source function, and it is given by

$$\delta(x-\alpha,y-\beta)=\delta(x-\alpha)\delta(x-\beta) \quad (2)$$

Thus the output of image is given by

$$\begin{aligned} g(x,y) &= F\left[f(x,y)\right]=\int\int_{-\infty}^{+\infty} f(\alpha,\beta)F\left[\delta(x-\alpha,y-\beta)\right]d\alpha d\beta \\ &= \int\int_{-\infty}^{+\infty} f(\alpha,\beta)h(x,\alpha,y,\beta)d\alpha d\beta \end{aligned} \quad (3)$$

Where $h(x,\alpha,y,\beta)=F\left[\delta(x-\alpha,y-\beta)\right]$ is referred to as Point Spread Function (PSF) or impulse response. The degradation of the image is because the impulse response of system is time-invariant. The output of image can be expressed by

$$\begin{aligned} g(x,y) &= F\left[f(x,y)\right]=\int\int_{-\infty}^{+\infty} f(\alpha,\beta)h(x-\alpha,y-\beta)d\alpha d\beta \\ &= f(x,y)*h(x,y) \end{aligned} \quad (4)$$

For a linear, time invariant, separable system, the image can be expressed as

$$g(x,y)=\int\int_{-\infty}^{+\infty} f(\alpha,\beta)h_1(x-\alpha)h_2(y-\beta)d\alpha d\beta \quad (5)$$

The degraded image with additive white noise can be expressed as

$$g(x,y)=\int\int_{-\infty}^{+\infty} f(\alpha,\beta)h(x-\alpha,y-\beta)d\alpha d\beta+n(x,y) \\ = f(x,y)*h(x,y)+n(x,y) \tag{6}$$

The frequency domain expression is obtained by

$$G(u,v)=H(u,v)F(u,v)+N(u,v) \tag{7}$$

where $G(u,v)$, $F(u,v)$, $H(u,v)$ and $N(u,v)$ represent the Fourier transform of $g(x,y)$, $f(x,y)$, $h(x,y)$ and $n(x,y)$.

3. The Method of Image Restoration by Wiener Filter

The Wiener filtering is optimal in terms of the mean square error. In other words, it minimizes the overall mean square error in the process of inverse filtering and noise smoothing [8-9]. The Wiener filtering is a linear estimation of the original image. The approach is based on a stochastic framework. In this section, the principle of Wiener filters is discussed in the frequency domain for the purpose of restoration of an image degraded by white noise. We assume that the output of the Wiener filter is $g(x,y)$, and can be represented by

$$g(x,y)=\sum_{m=-N}^{N}\sum_{n=-N}^{N} w(m,n)f(x+m,y+n) \tag{8}$$

Where $w(m,n)$ is weight of the Wiener filter, and can be found by minimizing

$$J=E\left[\left\{f(x,y)-g(x,y)\right\}^2\right] \tag{9}$$

Where E is denoted for expectation. However, in practice, the (9) is not easy to calculate, and is usually replaced by the following criteria

$$J=\frac{1}{M^2}\sum_{x=0}^{M-1}\sum_{y=0}^{M-1}\left\{f(x,y)-g(x,y)\right\}^2 \tag{10}$$

In the frequency domain, the Wiener filter is defined as

$$H(u,v)=\frac{P_f(u,v)}{P_f(u,v)+P_n(u,v)} \tag{11}$$

Where $P_f(u,v)$ and $P_n(u,v)$ represent the power spectra of $f(x,y)$ and $n(x,y)$ respectively. This solution is derived in a similar way with that in the space domain. By minimizing

$$J=E\left[\left|F(u,v)-G(u,v)\right|^2\right] \tag{12}$$

Where $F(u,v)$ and $G(u,v)$ represent the DFT of $f(x,y)$ and $g(x,y)$ respectively, the solution is first obtained as

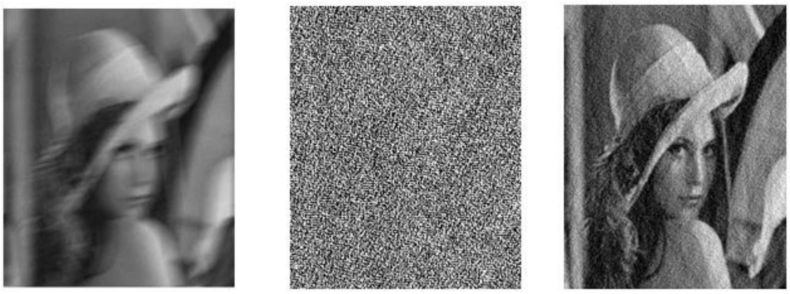
$$H(u,v)=\frac{E\left[G(u,v)D^*(u,v)\right]}{E\left[\left|G(u,v)\right|^2\right]} \tag{13}$$

Where $*$ denotes complex conjugate.

The Wiener filtering is applied to the image with a cascade implementation of the noise smoothing and inverse filtering. To illustrate the Wiener filtering in image restoration we use the standard 256×256 lena image. Firstly, the situation of image is tested without noise. A blurred image that you might get from camera motion, the simulation results of image are shown in Figure 2. Then the situation of image is tested with white noise. Let's try keeping the input image in uint8 representation instead of converting it to double. The simulation results of image are shown Figure 3.

(a) Standard Image (b) Blurred Image (c) Restored Image

Figure 2. The Image Restoration by Wiener Filter



(a) Blurred Image with Noise (b) Noise (c) Restored Image

(d) Quantized Image (e) Restored Image

Figure 3. The Image Restoration with Noise by Wiener Filter

Wiener filter yields the minimum-mean-square error between the restored image and the original image. However, to obtain an optimal result, there must be accurate knowledge of the power spectra of the noise and the original image besides the degradation function. Otherwise, it will lead to an undesirable restored result.

4. The Method of Blind Image Restoration

These all Wiener filters require a priori knowledge of the original image and noise power spectra. In most practical cases, however, such information is unknown or incompletely blind condition. As a result, noise estimation plays a central role in these Wiener filters and finally affects greatly the performance of Wiener filter. Blind deconvolution restore the higher spatial frequency content of degraded data with little or no a priori knowledge of the degradation [10-11].

The blind image restoration is the best estimate for the poor quality process and the original image from the observed image. Obviously, we can know that the blind image restoration is an ill-condition inverse problem. Because of the lack of information and the large amount estimation of information, it is very difficult to solve the problem. Caron [12] proposed a blind image restoration using SeDDaRA (Self-Deconvolution Data Reconstruction Algorithm), and it has good real-time performance. The power spectrum of image degradation is estimated directly from the power spectrum of the observed images by the power law, and the estimation of the original image is realized by using the classical image restoration algorithm.

For a space-invariant linear system, degraded image $g(x,y)$ can be represented in two dimensions by the convolution of the original $f(x,y)$ and the PSF $h(x,y)$ of the degradation process, plus an additive noise $n(x,y)$. Therefore

$$g(x,y) = f(x,y) * h(x,y) + n(x,y) \tag{14}$$

Where $*$ denotes two-dimensional convolution. In the frequency domain, (14) can be described as

$$G(u,v) = F(u,v)H(u,v) + N(u,v) \tag{15}$$

For a $N \times N$ sized image, the power-spectral density $W(u,v)$ is defined as

$$S_W(u,v) = \frac{|W(u,v)|^2}{N^2} \tag{16}$$

The transfer function $H(u,v)$ of a linear, space invariant system can be determined from the scaled α th power of the smoothed power-spectral of the degraded image .the process $H(u,v)$ can be extracted by SeDDaRA with the power law.

$$H(u,v) = KS\left\{\left[S_G(u,v) - S_N(u,v)\right]^{\alpha/2}\right\} \tag{17}$$

Provided that $H(u,v)$ is related to $F(u,v)$ according to

$$H^{1-\alpha}(u,v) = KS\left\{S_F^{\alpha/2}(u,v)\right\} \tag{18}$$

Where $S\{\cdot\}$ is a smooth operator, α is power exponent and is chosen by trial and error, K is a constant and is determined by $\max\left[H(u,v)\right] = 1$.

After getting the estimation of $H(u,v)$, the SeDDaRA algorithm use the classical Wiener filtering to obtain the estimation of original image in the frequency domain,

$$F(u,v) = \frac{H^*(u,v)G(u,v)}{|H(u,v)|^2 + k} \tag{19}$$

Where $H^*(u,v)$ is the conjugation of $H(u,v)$, k is a regularization factor and is chosen by trial and error. The original image of can be estimated by Fourier inverse transform.

A blind deconvolution technique has been developed that permits restoration and enhancement of degraded data. The process, designated the SeDDaRA, involves applying a Fourier transform to the degraded image, removing the phase information, applying a power law, and transforming the image back into real space. To illustrate the SeDDaRA algorithm in image restoration we use the standard lena image. The simulation result of image is shown Figure 4.

(a) Standard Image **(b) Blurred Image** **(c) Restored Image**

Figure 4. The Blind Image Restoration by SeDDaRA Algorithm

It is clear that the SeDDaRA algorithm has good real-time performance because the algorithm uses the power law to extract the estimation of the degradation process, and is not the iteration of the algorithm to achieve the blind restoration of degraded images. Through the above knowledge, the realization of SeDDaRA algorithm includes 2D-FFT, power operation, smooth operation, Wiener filtering and 2D-IFFT. The block diagram of hardware implementation is shown in Figure 5. 2D-FFT module is mainly responsible for the transformation domain of the image. Power operation module is mainly worked for the estimation of $H(u,v)$. The main function of median filter is the smooth operation for $H(u,v)$.

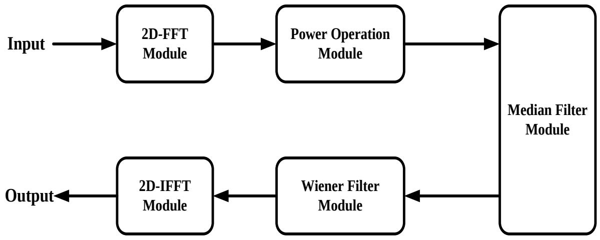


Figure 5. The Implementation Block Diagram of SeDDaRA Algorithm

5. The Implementation of Blind Image Restoration by MBD

With the development of microelectronics technology, the design of embedded system is becoming more and more complex. People are increasingly demanding for real-time of electronic products, which greatly increased the complexity and difficulty of embedded systems product development. If adopted the traditional development flow, it is not conducive to the development of efficient, high-quality products in the fierce competition of market. In addition, different departments shall be responsible for different processing and communication between departments easily lead ambiguity through paper document. Errors will be transferred and influence the progress of the development flow. if there is a problem, the problem need to be analyzed and validated for a long time due to testing in the completion of the entire design. If the problem occurs at the beginning of the design, the whole design cycle and cost bring great negative effects.

In the MBD [13-14], a system model is at the center of the development process, from requirements development, through design, implementation, and testing. The development flow by MBD is shown in Figure 6. Through the establishment of floating point model, the fixed-point model and the system-level model for presenting a complete system design requirements, different professional engineers work efficiently, and can communicate at different stages of the development flow.

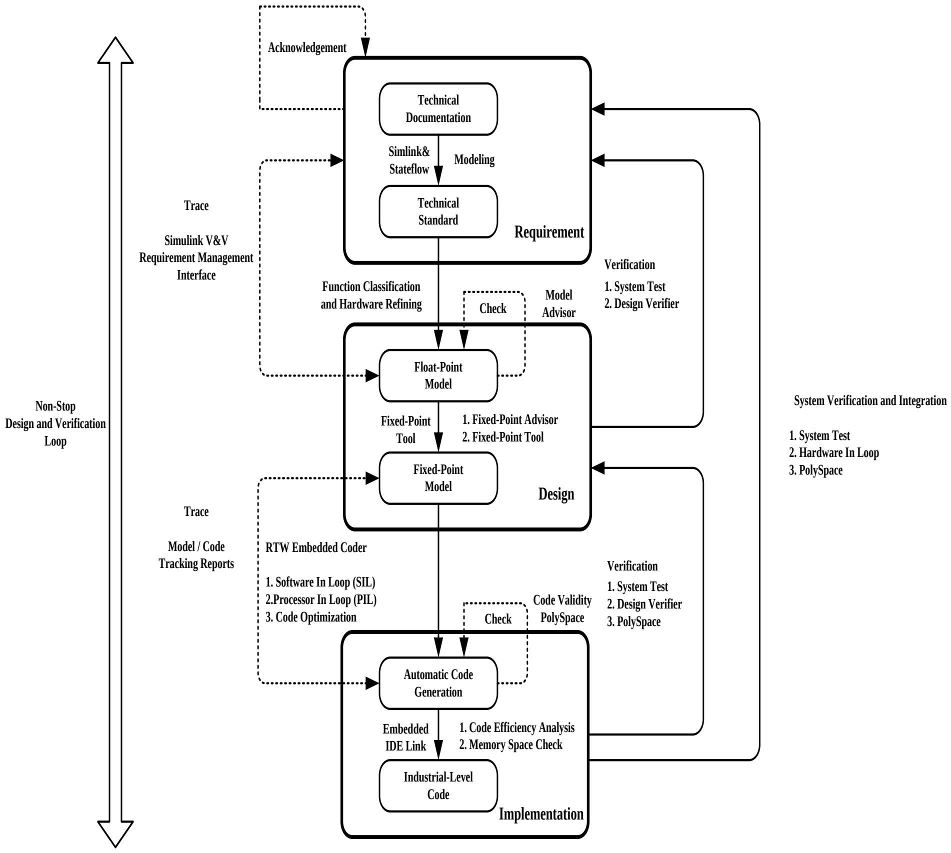
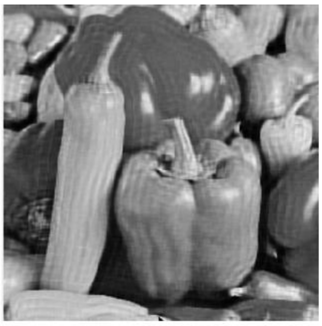


Figure 6. The Development Flow by MBD

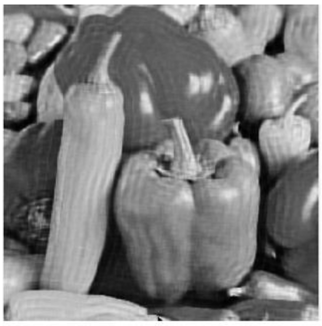
The HDL Coder is an excellent development tool of MBD, and is a plug-in to Simulink. With HDL Coder, developers with little FPGA design experience can quickly create production level RTL code for implementations of algorithms using FPGA. According to the diagram block of SeDDaRA algorithm in the Figure 5, the whole blind image processing system is built by System Generator, and it is shown in Figure 7.

(a) Standard Image

(b) Blurred Image



(c) Restored Image with Simulink



(d) Restored Image with FPGA

Figure 7. The Contrast of Restoration between Software and Hardware

Conclusion

In this paper, blind image restoration is a kind method of image processing by estimating both the original image and the point spread function from degraded images, when there is unknown or not completely know the prior knowledge of the original image and point spread function of imaging. However, blind image reconstruction is a very complex process, and the hardware implementation is very difficult. The SeDDaRA algorithm is used to simplify the process of the reconstruction of the blind image, and the image processing system is built by the method of MBD. The simulation results show that the proposed algorithm is not only simple in structure and easy to implement, and can improve the processing speed with good scalability.

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