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Research on the Implementation of Image Degradation and Restoration by using Model-Based Design Methodology

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Abstract

The degradation and restoration of image are very important and widely studied in the field of computer visualization and image processing. The key of image restoration is to analyze the cause of image degradation, and to establish a reasonable model. The cause of image degradation is described by reasonable degradation model and specific parameters. In this paper, the linear image degradation model and common image restoration methods are described, and the system of image degradation model and image restoration is built. The simulation results show that the system of image degradation and restoration using Model-Based Design (MBD) methodology is not only efficient and simple, and convenient for hardware implementation.

Keywords: *Degradation, Restoration, Inverse filter, Weiner filter, Model-Based Design*

1. Introduction

In the acquisition of images, the poor of camera focus, or the noise from the sensor, atmospheric turbulence, dust and light and shade, which will cause the degradation of the image, in order to extract useful information from fuzzy images, image restoration has become important in image processing, and it is an important application in the digital image processing.

The purpose of image restoration is to reconstruct the original image from the degraded image. Image restoration is based on the attempt to improve the quality of an image through knowledge of the physical processes which led to its formation. We may consider image formation as a process which transforms an input distribution into an output distribution. The input distribution represents the ideal. It is the perfect image to which we do not have direct access but which we wish to recover or at least approximate by appropriate treatment of the imperfect or corrupted output distribution. At present, image restoration is the basis of image processing, pattern recognition, machine vision and so on, and widely studied in the astronomy [1], remote sensing imaging [2], application of medical image [3-5].

The rest of this paper is structured as follows. Section 2 describes the basic model of image degradation in a linear imaging system. The model not only considers the factors of the system itself, but also considers the noise pollution. Section 3 discusses the method for image restoration based on inverse filter. The Fourier transform of the original image is estimated by the Fourier transform of a fuzzy image. Section 4 demonstrates restoration algorithm by Wiener filter. This algorithm is built on the basis of minimizing statistical rules, and the result obtained is only the optimal in the sense of average. Section 5 expounds the Implementation of image degradation and restoration by the methodology of MBD. Finally, concluding remarks are drawn in Section 6.

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2. The Degradation Model of Image

In this section, we describe the basic model of image degradation by noise in a linear imaging system. Through this paper, we assume that $f(x,y)$ and $g(x,y)$ represent the input and output of image, respectively. A pair of images can be regarded as a series of point source [6] [7]. So $f(x,y)$ can be expressed by the convolution of the point-source function, and it is represented by

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

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

$$\delta(x-\alpha,y-\beta)=\delta(x-\alpha)\delta(x-\beta) \tag{2}$$

thus the output of image is given by

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

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

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

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

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

In addition to the factors of the system itself, the image degradation is sometime disturbed by the noise. Generally we assumed noise $n(x,y)$ is additive white noise. The model of degradation of image is shown in Figure 1.

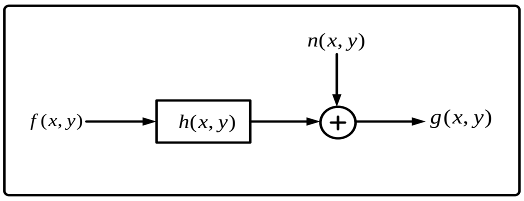


Figure 1. The Model of Image Degradation

The degraded image with additive white noise can be expressed as

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

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 for Image Restoration Based On Inverse Filter

The purpose of image restoration is to compensate for or undo defects which degrade an image. Degradation comes in many forms such as motion blur, noise, and camera misfocus aberration. In cases like motion blur, it is possible to come up with a very good estimate of the actual blurring function and "undo" the blur to restore the original image. In cases where the image is corrupted by noise, the best we may hope to do is to compensate for the degradation it caused. The filtering method of image restoration is to find a filter transfer function by some method. First of all, the Fourier transform of the image is obtained, and then the image is reconstructed by Fourier inversion transform in the frequency domain for image filtering. The whole model is shown in Figure 2.

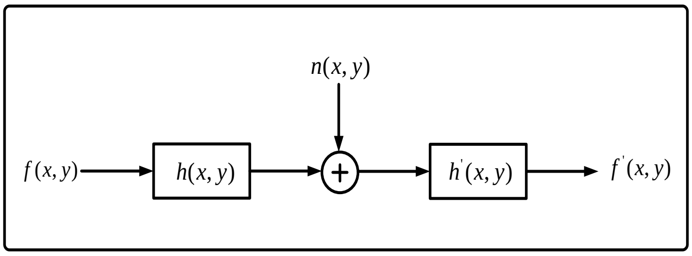


Figure 2. The Model of Image Restoration

Consider again the linear time invariant （LTI） imaging equation presented in equation (6), and If the impact response of the system is $h_T(x,y)$, the image restoration can be expressed as

$$f'(x,y) = g(x,y) * h_T(x,y) = [h(x,y) * f(x,y) + n(x,y)] * h_T(x,y) \tag{8}$$

By convolution theorem, the corresponding Fourier transform is given by

$$F'(u,v) = [H(u,v)F(u,v) + N(u,v)]H_T(u,v) \tag{9}$$

Assuming that the transfer function of image restoration is represented by

$$H_T(u,v) = \frac{1}{H(u,v)} \tag{10}$$

Where $H(u,v)$ the system is optical transfer function (OTF) is called the inverse filter [8], and (9) can be expressed as

$$F'(u,v) = F(u,v) + \frac{N(u,v)}{H(u,v)} \tag{11}$$

Equation (11) shows that our recovered frequency spectrum has an additional term: the noise spectrum $N(u,v)$ divided by the system $H(u,v)$. Clearly, we would like this additional term to be as small as possible, since the estimated spectrum will then approach the true input spectrum. The noise spectrum, however, is an unknown and random addition to the data to output image spectrum. Moreover, it is characteristic of many noise processes that they have significant high-frequency content. In this case, it is clear that the first term on the right-hand side in equation (11) will be completely dominated by the second term.

In order to avoid the smaller value of $H(u,v)$, the image can be restored in the near of finite field, or the second item of the equation (11) is multiplied by a weighting function $W(u,v)$, and $W(u,v)$ is described as

$$W(u,v)=\begin{cases}1, & F(u,v)>\dfrac{N(u,v)}{H(u,v)}\\[2ex] 0, & F(u,v)<\dfrac{N(u,v)}{H(u,v)}\end{cases} \tag{12}$$

It can restrain the noise amplification, and keep the details of high frequency image at the same time.

4. The Method for Image Restoration Based On Wiener Filter

The inverse filtering is a restoration technique for DE convolution, when the image is blurred by a known low-pass filter; it is possible to recover the image by inverse filtering or generalized inverse filtering. However, inverse filtering is very sensitive to additive noise. The approach of reducing one degradation at a time allows us to develop a restoration algorithm for each type of degradation and simply combine them. The Wiener filtering executes an optimal tradeoff between inverse filtering and noise smoothing. It removes the additive noise and inverts the blurring simultaneously [9].

The Wiener filtering is optimal in terms of the mean square error [10]. In other words, it minimizes the overall mean square error in the process of inverse filtering and noise smoothing. The Wiener filtering is a linear estimation of the original image. The approach is based on a stochastic framework. The Wiener filter is a filter, which makes minimum variance between the original image $f(x,y)$ and the restoration image $f^{'}(x,y)$, and it is defined as follows

$$E\left\{\left[f(x,y)-f^{'}(x,y)\right]^2\right\}=\min \tag{13}$$

$E\{\ \}$ Is a mathematical expectation operator, If there is uncorrelated between $f(x,y)$ and noise $n(x,y)$, and the mean value of $n(x,y)$ is zero, the transfer function of the Wiener filter can be obtained by

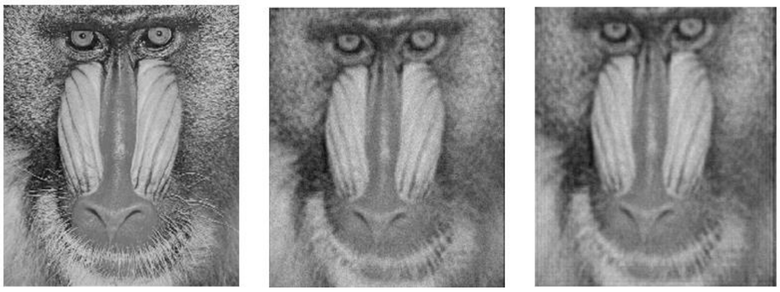
$$H_W(u,v)=\frac{H^*(u,v)}{\left|H(u,v)\right|^2+\dfrac{P_n(u,v)}{P_f(u,v)}} \tag{14}$$

Where $H^*(u,v)$ denotes the complex conjugate of the OTF. $P_n(u,v)$ And $P_f(u,v)$ are respectively the input and noise power spectra, the restored image $F^{'}(u,v)$ can be expressed as

$$F^{'}(u,v)=H_W(u,v)G(u,v)=\frac{H^*(u,v)}{\left|H(u,v)\right|^2+\dfrac{P_n(u,v)}{P_f(u,v)}}G(u,v) \tag{15}$$

Equation (15) thus shows clearly that the Wiener filter approximates an inverse filter for those frequencies at which the signal/noise power ratio is large, but becomes increasingly small for spatial frequencies at which the signal-noise power ratio is small.

To illustrate the Wiener filtering in image restoration we use the standard 256×256 baboon test image. The image was degenerated with the low-pass filter. Then put into the degenerated image the additive white Gaussian noise of variance 100. The Wiener filtering is applied to the image with a cascade implementation of the noise smoothing and inverse filtering. The images are listed as shown in Figure 3 with the PSNR and MSE. Notice that the restored image is improved in terms of the visual performance, but the MSE don't indicate this, the reason of which is that MSE is not a good metric for DE convolution.



(a) Standard baboon Image PSNR = Infinity MSE = Zero

(b) Blurred baboon Image PSNR = 19.4519 MSE = 737.7175

(c) Restored baboon Image PSNR = 18.2423 MSE = 974.6629

Figure 3. The Effect of Image Restoration by Wiener Filter

The restoration method by Wiener filter can be obtained satisfactory results in most cases, but the effect is often unsatisfactory when the SNR is low. It may be because that the Wiener filtering is based on stationary stochastic process model, and the degradation model is linear time invariant system.

5. Image Degradation and Restoration Using Model-Based Design

The Traditional embedded design development involves paper designs and hand coding, followed by verification activities such as code inspections and a unit/integration test. Many of these activities lack tool automation, and so involve manual interaction. Thus they are error prone and time consuming. Lack of tool chain integration provides another opportunity for errors to be injected into the software that are often detected late and at high costs to the development process. To overcome these challenges, Model-Based Design (MBD) has become a widely used and accepted approach. Not only do simulations provide insight into the dynamic and algorithmic aspects of the system, but models are also commonly used for several constructive tasks.

In the MBD, a system model is at the center of the development process, from requirements development, through design, implementation, and testing. MBD improves design quality and accelerates design and verification tasks by employing an executable specification. This executable specification is elaborated to create hardware and software partitioning, automatically create hardware and software implementation code, and verify the hardware and software implementations in the context of the complete system. The development flow by MBD is shown in Figure 4. Significant advantages of MBD include the fact that it facilitates rapid design iterations and it moves the verification process all the way to the beginning of the design cycle. This helps detect system specification related errors, design errors, and implementation errors early.

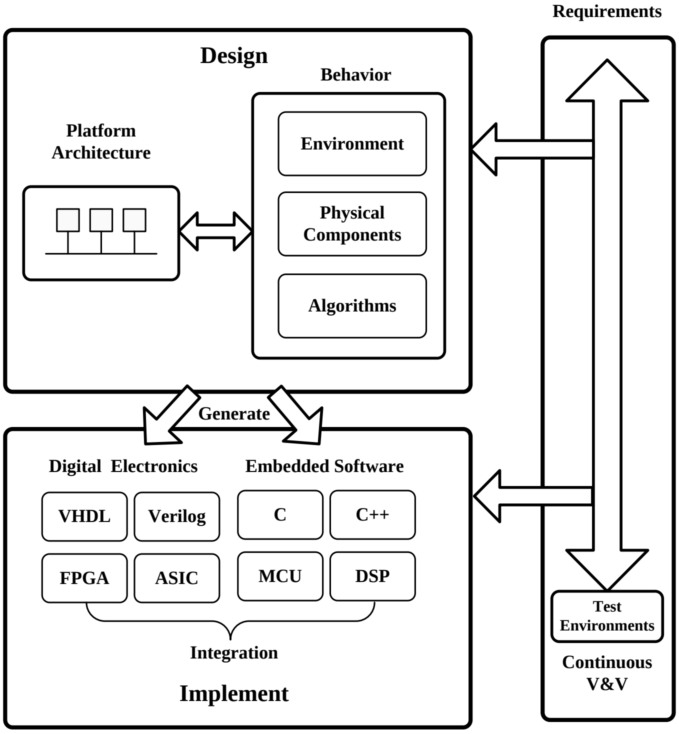


Figure 4. The Development Flow by MBD

The Xilinx System Generator is an excellent development tool of MBD, and is a plug-in to Simulink. With System Generator, developers with little FPGA design experience can quickly create production quality FPGA implementations of algorithms in a fraction of traditional RTL development. The tool will then automatically generate synthesizable Hardware Description Language (HDL) code mapped to Xilinx pre-optimized algorithms. System Generator design flow is shown in Figure 5. This HDL design can then be synthesized for implementation on Xilinx FPGA and All Programmable SOC. As a result, designers can define an abstract representation of a system-level design and easily transform this single source code into a gate-level representation. Additionally, it provides automatic generation of a HDL test-bench, which enables design verification upon implementation.

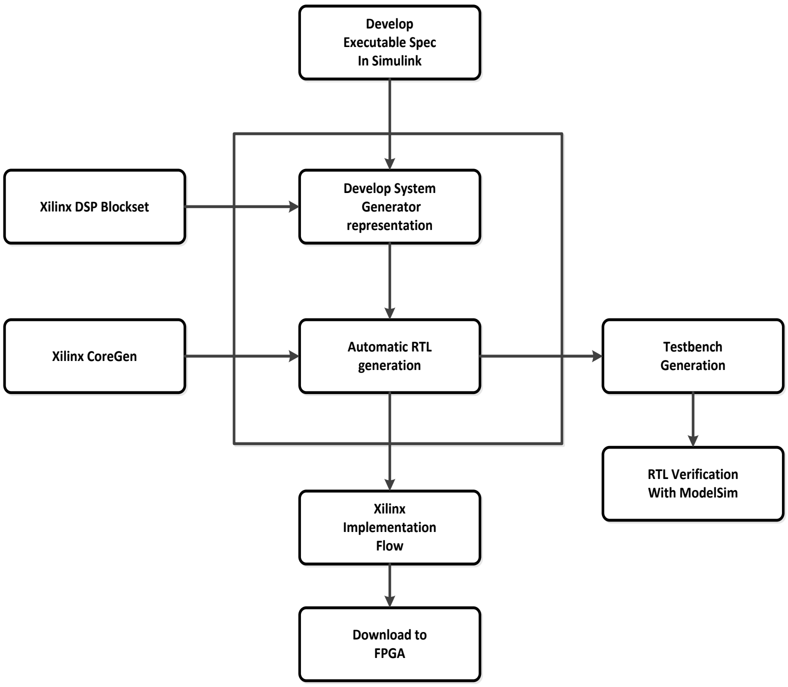


Figure 5. System Generator Design Flow

The model of image degradation is built by System Generator, and the degradation model is a horizontal motion-blur. Convolution formula can be simplified to

$$g_n = \sum_{k=n-l}^{n} a_k / l \tag{16}$$

Where a the original image pixel is value; g is the pixel value of the degraded image; l is the convolution length, and the value is 4. In practice, the ambiguity of the horizontal motion by the image capture device can be summarized as the above degradation model. The image degradation model constructed by System Generator is shown in Figure 6.

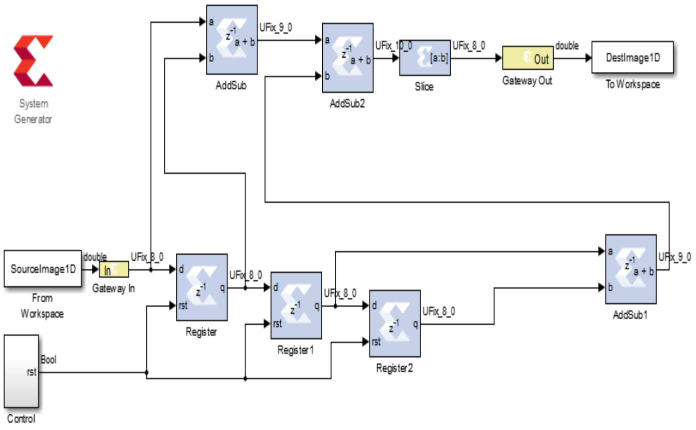


Figure 6. The Model of Image Degradation

The three Register modules of model realize the shift register, which complete the line operation of convolution. Due to the line operation of convolution, the Control module is responsible for the pixels of row, and provides a reset signal. The original image is shown in Figure 7, after degradation model, horizontal motion blurred image is shown in Figure 8.

Figure 7. The Original Image

Figure 8. The Degraded Image

Image restoration is used by the System Generator for the degraded images. According to (16), the time-domain DE convolution of image restoration corresponding degradation model can be expressed as

$$a_n^{'} = \sum_{m=0}^{M} g_{n-ml} - g_{n-ml-1} \times l \tag{17}$$

Where g is the pixel of image degradation; $a^{'}$ is the pixel of restoration image; M is n/l rounded down; l is the length of convolution, and the value is 4. The image restoration model constructed by System Generator is shown in Figure 9.

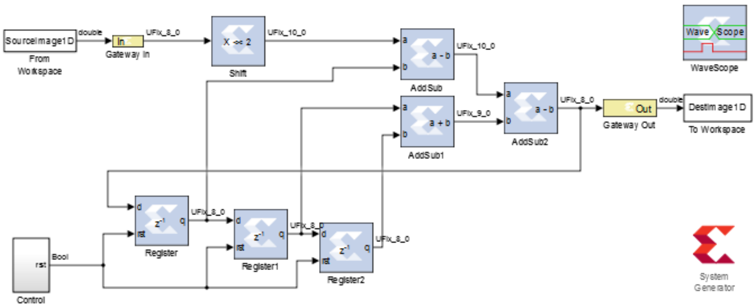


Figure 9. The Model of Image Restoration

The restored pixel of image is used as the input of the shift register in the model, and the Control module provides a reset signal for registers. The restored image and the original image are shown in Figure 10 and Figure 11. Because of the loss of part of the image degradation, so it cannot recover the same results with the original image.

Figure 10. The Original Image

Figure 11. The Restored Image

6. Conclusion

Image restoration refers to the restoration of the image because of quality decline, and removes the influence of the degradation in the image. In this paper, we introduce the basic principle of image degradation and image restoration, and give the method of inverse filtering restoration and the method of Wiener filtering for image restoration. However, it is very difficult to implement the image restoration algorithm by hardware. This paper uses the method of MBD to build the image degradation model and the time domain recovery model and provides a new design method for the hardware implementation of image restoration. Experimental results show that the method is effective and simple, and has a certain reference value for engineering.

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