DIGITAL IMAGE DEBLURRING TECHNIQUES: A COMPREHENSIVE SURVEY

Maxim COJOCARI-GONCEAR

Department of Software Engineering and Automation, group FAF-213, Faculty of Computers, Informatics and Microelectronics, Technical University of Moldova, Chisinau, Republic of Moldova

Corresponding author: Maxim Cojocari-Goncear, maxim.cojocari-goncear@isa.utm.md

Abstract. *Blur in images is the most challenging issue in image processing, which is caused via multiple external factors. Deblurring is the most important process in restoring the sharpness of the original image, so many approaches and techniques were proposed. This paper covers a spectrum of strategies that are related to software applications for image deblurring restoration. The aim of this research is to reveal the logic behind the current algorithms and techniques in this field, helping the researchers to develop more efficient algorithms for corresponding purposes.*

Keywords: *digital image, blur, deblurring, noise, filter*

Introduction

Nowadays, millions of images are captured at milliseconds, in various conditions and circumstances. Therefore, there is a high probability of blur emergence in visual data. The blur, which is the focus of this paper, may be caused by high-resolution methods degrading obtained picture quality. When distortion and blur are removed, the results of picture deblurring could be a clean image. Blurring may be caused by a range of things, such as noise, dust, the atmosphere, camera movement, object movement [1]. Therefore, image deblurring is of the paramount importance within the field of image processing.

Deblurring methods are classified into non-blind and blind ones. Within the state of blind deblurring, the blurring kernel is unknown while within the variety of non-blind, previous knowledge of the blurred kernel and related parameters are known [2, 3].

The sections in this article are arranged in the following order: in the first section are presented main blur models and their mathematical glance. The section two reveals in detail the deblurring methods: their description, usage cases, some advantages and disadvantages.

Blur Models

The two most common causes of image quality loss in digital imaging is motion blur. Image quality in low-light situations is always a balance between motion blur and noise. Motion blur can occur when the camera or the subject moves during the exposure time. Meanwhile, the subject's picture moves to various sections of the photosensitive surface of the camera sensor. Negligible camera motions soften the image and reduce the number of details, whereas greater movements might render the entire image unreadable [4].

Relevant to our discussion are parameters that define the spatial characteristics of blur. The following are the most common models of blur found in image processing applications.

a. Gaussian blur

When using the Gaussian function in image processing, the picture may seem blurry (also Gaussian use for image smoothing). The Gaussian blur is a filter that gradually combines a set number of pixels in a bell-shaped curve fashion. The majority of Gaussian blur is based on slandered deviation.

The probability distribution function of a Gaussian random variable z is given by

$$p(z) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(z-\mu)^2}{2\sigma^2}\right) \quad (1)$$

If we consider an arbitrary image, z axis represents the intensity values along which we distribute the noise pixel values, μ is the mean of the average of z, and σ is its standard deviation. The standart deviation squared, σ^2, is called the variance of z [3].

b. Average blur

Average blur affects the entire image. It can be spread in horizontal and vertical direction, and calculated by a circular averaging of radius R that can be computed using Eq. (2):

$$R = \sqrt{g^2 + f^2} \quad (2)$$

where g represents the horizontal blurring, f represents the vertical blurring, and R represents the radius of the circular medium blurring [5].

c. Motion blur

The deterioration of an image produced by relative motions between the camera and the object during the capture is known as motion blur. Various forms of motion blur can be distinguished by the relative movement between the camera and the scene. A transition, rotation, or sudden shift in size, or a combination of these, might be the case [6].

d. Out-of-focus blur

Blurring can occur when an object in a photo is outside the depth of the camera owing to exposure. When a camera records a 3D scene on a 2D image plane, certain components of the scene are focused while others are not.

e. Atmospheric turbulence blur

Atmospheric turbulence is one of the most prevalent causes of visual distortion. It arises in the imaging of celestial objects because of random fluctuations in the medium's reflecting index in which the object and the imaging device are immersed. The amount of blur produced by air turbulence is dependent on a number of parameters, including temperature, wind speed, and exposure duration. Stars in outer space, for example, seem blurry when viewed via telescopes because of the Earth's atmosphere layered structure which decreases visual quality of the image [5, 7].

Deblurring Techniques

Deblurring is a technique to remove artifacts from images that are affected by blur. Image deblurring can broadly divide into two classes, specifically blind and non-blind deconvolution, as presented in Fig. 1.

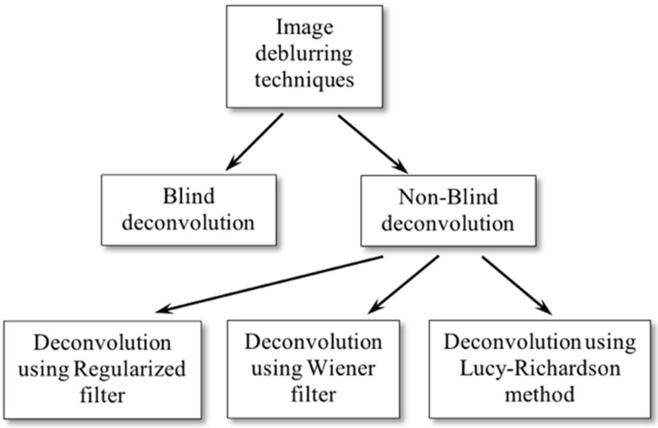

Figure 1. Classification of image deblurring techniques [8]

a. Wiener filter

The best feasible balance of noise smoothing and reverse filtering can be achieved using Wiener filtering. It eliminates additive noise while also reversing picture blurring. It can be used properly only after the frequency characteristics of the image and additive noise are understood to some level. In the absence of noise, the Wiener filter simplifies to the classical inverse filter [9]. This filter reduces the mean square error between the estimated random process and the intended process. The Wiener filter can also be coupled with the fast Hartley transform (FHT) in order to speed up the deblurring process. The results of motion deblurring using this approach are shown in Fig. 2, where a – original image, b – blurred image, c – restored image via Wiener filtering.

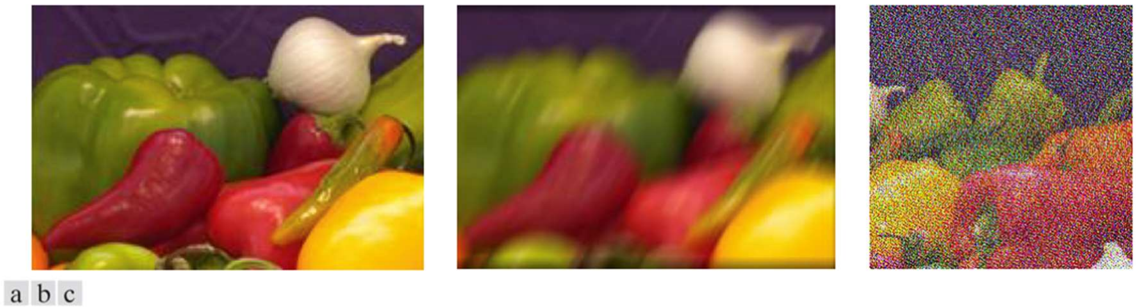

Figure 2. Deblurring images using Wiener filter [8]

b. Lucy-Richardson algorithm (LR algorithm)

The Richardson-Lucy deconvolution algorithm is a popular restoration approach used in the digital image industry. In the early 1970s, Leon Lucy and William Richardson developed this algorithm using Bayes's theorem as a reference. When the point spread function (PSF) is known, but there is little or no information about the noise, the LR technique can be employed adequately. Because the LR method is an iterative process, shows up the question how many times the process should repeat. Too many iterations will slow down the algorithm and additional noise, ringing effects can occur. The inclusion of optical device features may be used as input parameters in order to increase the effectiveness of picture restoration [3,8].

c. Regularized filter

The regularized filter is another type of a non-blind deconvolution. When using the Wiener filter, an additional challenge may arise: knowing the power spectra of the degraded image and noise. The regularized filter, together with the constrained least square restoration algorithm is an appropriate solution in this scenario since it simply requires knowledge of the noise's mean and variance, thus producing almost satisfactory results in many situations [3].

In order to summarise, the main advantages and disadvantages of non-blind deconvolution techniques are shown in Tab. 1.

Tabel 1

Non-blind deconvolution techniques

Type	Advantages	Disadvantages
Wiener filter	• It gives great results when the variation of image parameters is small considering the presence of Gaussian white noise; • It's efficient when the PSF is almost known, based on the condition that noise can be easily estimated.	• May not give the proper result if there is no given PSF, at least approximately; • Great results are reachable only if no noise is present.
Lucy-Richardson alg.	• It's extremely popular because of its straightforward implementation and the ability to create high-quality reconstructed pictures in the midst of high noise levels [10]; • When the PSF isn't known exactly or just an estimate is given, the recovered image is resilient to minor changes or inaccuracies in the PSF.	• It's sensitive to kernel miscalculation, so it may produce ringing objects; • Images damaged by a convolution kernel and instances which have a non-valid PSF will not be restored by the LR algorithm.
Regularized filter	• This strategy is perfect when there is just a limited amount of information concerning noise; • Together with the constrained least square restoration algorithm, it produces a suitable outcome for every image to which it is applied.	• It's too sensible for input parameters: for wrong noise parameters it fails; • Because it is an automatically determined restoration filter, it doesn't mean that the optimum restoration will be the best in visual sense: it may yield inferior results to manual adjustment of filter parameters [3].

Blind deconvolution approach

The blind deconvolution method is beneficial when no information about the PSF or blur operator is available. It will restore the picture as well as the resultant PSF at the same time. Blind deconvolution can be classified into two types: projection based and maximum-likelihood method. The first technique restores both the real picture and the PSF parallelly. This begins with preliminary estimates of the original picture and PSF. Consecutively it finds the image estimation and then the PSF estimation. This cyclic approach iterates until the convergence standard is fulfilled. The advantage of this approach is that it appears to be resistant to support size inaccuracy, and it is also unaffected by noise parameters. Nevertheless, some unpleasant difficulties may appear. The risk of a mistake in local minima exploration is a weakness of this strategy. In the second method, the maximum likelihood is identified for the parameters such as PSF and covariance matrices. Because the estimated PSF is not unique, we may examine additional factors such as the size, symmetry, and other characteristics of the calculated PSF. The low computing complexity of this approach is one of its key advantages, and it also aids in the detection of blur, noise, and power spectra in the original picture [11].

The comparison between blurry images that were filtered using non-blind deconvolution and blind deconvolution methods can be clearly observed in Fig. 3.

a b c

Figure 3. The results of various deblurring filters: a – LR filter, b – regularized filter, c – blind deconvolution [8]

Conclusion

By analyzing a significant number of methods which have been developed by various researchers for image deblurring and image restoration, we detected some of their advantages and disadvantages and underlined their practical usage and importance. In recent years, the majority of papers covered blind image deblurring algorithms because of their great performance. And this can be proven by a comparative visual analysis of the obtained images in this paper. Of course, the non-blind deconvolution techniques are also great in specific circumstances. But together with blind deconvolution methods they can brilliantly restore the blurred images in an effective way. Future scope is to develop a novel, hybrid model which can deal with a complex deblurring process without huge computational and memory resources.

References:

1. ABDUL, A., DAWOOD, M., SALEH, M. F., Image Deblurring Techniques : A Review. In: *Journal of Scientific and Engineering Research* [online]. 2019, 6 (3), pp. 94–98. [accessed 22.02.2022]. Available: https://www.academia.edu/40363052/Image_deblurring_tecniques
2. GOWTHAMI, S., HARIKUMAR, R., Conventional neural network for blind image blur correction using latent semantics. In: *Soft Computing - A Fusion of Foundations, Methodologies and Applications* [online]. 2020, 24, pp. 15223-15237. [accessed 23.02.2022]. Available: http://doi.org/10.1007/s00500-020-04859-y
3. GONZALEZ, R., WOODS, R., Image Restoration. In: Gonzalez, R., Woods, R., *Digital image processing*, 2nd Edition, Prentice Hall, Upper Saddle River, 2002, pp. 220-281.
4. KURIMO, E., LEPISTÖ, L., NIKKANEN, J., GRÉN, J., KUNTTU, I., LAAKSONEN, J. The Effect of Motion Blur and Signal Noise on Image Quality in Low Light Imaging. In: *Image Analysis. SCIA 2009. Lecture Notes in Computer Science* [online]. 2009, 5575, pp. 81-90. [accessed 23.02.2022]. Available: https://doi.org/10.1007/978-3-642-02230-2_9
5. JAIN, S., GOSWAMI, M.S. A Comparative Study of Various Image Restoration Techniques with Different Types Of Blur. In: *International Journal of Research in Computer Applications and Robotics* [online]. 2015, 3(11), pp. 54-60. [accessed 23.02.2022]. Available: https://www.ijrcar.com/Volume_3_Issue_11/v3i1111.pdf
6. MARU, M., PARIKH, M., Image Restoration Techniques: A Survey. In: *International Journal of Computer Applications* [online], 2017, 160(6), pp. 15-19. [accessed 23.02.2022]. Available: https://doi.org/10.5120/ijca2017913060
7. DEVI, M.K., ASHWINI, R. An Analysis on Implementation of Various Deblurring Techniques in Image Processing. In: *International Research Journal of Engineering and Technology* [online]. 2016, 3(12), pp. 1049-1059. [accessed 23.02.2022]. Available: https://www.irjet.net/archives/V3/i12/IRJET-V3I12241.pdf
8. YADAV, S., JAIN, C., CHUGH, A. Evaluation of image deblurring techniques. In: *International Journal of Computer Applications* [online]. 2016, 139(12), pp. 32-36. [accessed 26.02.2022]. Available: https://doi.org/10.5120/ijca2016909492

9. TIWARI, S., SHUKLA, V.P., SINGH, A., BIRADAR, S.R. Review of Motion Blur Estimation Techniques. In: *Journal of Image and Graphics* [online], 2013, 1(4), pp. 176-184. [accessed 26.02.2022]. Available: https://doi.org/10.12720/joig.1.4.176-184
10. FISH, D. A., BRINICOMBE, A. M., PIKE, E. R., WALKER, J. G. Blind deconvolution by means of the Richardson–Lucy algorithm. In: *Journal of the Optical Society of America A*, 1995, 12(1), pp. 58-65.
11. MANE, M.A. Removing blur from degraded image with blind deconvolution using canny edge detecting technique. In: *International Journal of Innovative Research in Advanced Engineering* [online]. 2014, 1(11), pp. 50-55. [accessed 26.02.2022]. Available: http://www.ijirae.com/volumes/vol1/issue11/09.NVEC10112.pdf