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ABC optimized neural network model for image deblurring with its FPGA implementation

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ABSTRACT

Image deblurring is indispensable to many image processing applications. In this paper, we try to improve radiological images degraded during acquisition and processing. An autoregressive moving average (ARMA) model, used for nonlinearly degraded image deconvolution, is identified using a neural network (NN). The NN training is improved using a novel swarm optimization algorithm called Artificial Bees Colony (ABC), inspired from the foraging intelligence of honey bees. The ABC has the advantage of employing fewer control parameters compared to other swarm optimization algorithms. Both estimated image and blur function are identified through this representation. The optimized ARMA-NN model is then implemented on a Xilinx reconfigurable field-programmable gate array (FPGA) using hardware description language: VHDL. This VHDL code is tested on the rapid prototyping platform named ML505 based on a Virtex5-LXT FPGA chip of Xilinx. Simulation results using some test and real images are presented to sustain the applicability of this approach compared to the standard blind image deconvolution (BID) method that maximizes the likelihood using an iterative process. A statistical comparison is concluded based on performance evaluation using seven recent image quality metrics.

1. Introduction

Radiology is discovering the human body by means of images. Although radiology began with the use of X-rays, the present radiologist now has a diversity of tools for taking images of patients. Many of these recent tools generate an image with a computer and some do not use any X-rays, or radiation of any kind such as Magnetic Resonance Imaging (MRI) and Ultrasound (US). Instead, MRI is a technique that combines a large magnetic field and some radio frequency coils. The pictures look like sections or cuts. Basic radiographs can be produced using a variety of imaging techniques, and they all need exposing the patient to X-ray radiation. Computed Tomography (CT) is a specific X-ray imaging technique, it makes the image by using a collection of small X-ray sensors and a computer. By spinning the X-ray source and the sensor around the patient, data is gathered from many angles. Nuclear medicine involves making the patient momentarily radioactive, with a little quantity of an isotope. The images are obtained by determining the patient radioactivity. Angiography is the procedure that produces an image of blood vessels inside the body. Image in any form was never an accurate representation of the examined object since it is always degraded by the imaging system itself. In radiology, there are several components tend to corrupt the image, then limiting the resolution of such images. The degradation sources in radiology are geometric unsharpness due to the lack of beam collimation, statistical fluctuation owing to low intensities or high background, motion unsharpness due to object motion during exposure, and limitations in acquisition/processing systems. To overcome these problems, deconvolution is a solution to reduce the blurring and noise effects on the image.

Image deconvolution methods are different from those of image enhancement. Deconvolution techniques try to perform an inverse transformation of the observed degraded image to estimate the original one. Because of this approach, they are oriented towards modeling degradations, in order to apply an inversion technique. In practice, exact reconstruction of the original, from the observed image data, may be impossible, even with knowledge of the degrading system characteristics. This is due to the ill-posed nature of the image deblurring problem, and the presence of noise. Authors of [1,2] did a comparative study between some state of the art approaches to select an image deconvolution method, and they got good results by introducing two swarm intelligence algorithms in the optimization step. The process of simultaneously estimating the degradation function and deblurring an unknown image using partial or no information about the imaging system is known as blind image restoration [3]. Blind deconvolution technique was another restoration method in image processing field.

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Authors of [4] developed an iterative, accelerated, damped algorithm to enhance the Neutron Computed Tomography images by iterative de-blurring of neutron transmission projections. They minimized the square of the difference in pixel count between the original and blurred predicted image, and they concluded that this approach can be used effectively when the point spread function PSF (blurring operator) is known, but little or no information is available for the noise. Authors in [5] combined Haar wavelet and Lucy–Richardson algorithm to restore positron emission tomography (PET) images. This implementation enhanced the contrasts of images without much amplifying much the noise level in this ill-posed deconvolution problem. Authors in [6] used iterative Constrained Least Squares algorithm for both blur identification and image restoration in blind restoration of images degraded by space-variant blurs. They extended the Expectation–Maximization (EM) algorithm and combine it with the region adaptive technique to handle the problem of identifying spatially variant blurs. They got good estimate with reduced artifacts in restored images in addition to blur identification. Authors in [7] investigate the image blur estimation methods, and apply that to X-ray radiological images, and they concluded that the accuracy of the PSF estimation under the Poisson noise and readout electronic noise is significantly better for the R–L estimator than the Wiener estimator. Blind deconvolution using ARMA parameter estimation methods involves modeling the true image as a two-dimensional AR process and the blurring function as a two-dimensional MA process. Based on these models, the resulting blurred image is represented as an ARMA process. Identifying the ARMA parameters allows identifying both the true image and the degradation function [8]. Based on a novel 2D-ARMA parameter estimation, this paper propose a neural network model for fast blind image restoration. The proposed approach can overcome local minimization problem by using particle swarm optimization (PSO) algorithm. Comparison with iterative blind deconvolution based on results, shows that the proposed approach can obtain a better image estimate with a faster speed than the BID algorithm. Maximum likelihood (ML) [9–10], generalized cross validation (GCV) [11] and neural networks [12] are three popular methods that are employed to determine these parameters. The disadvantage of both ML and GCV lies in the higher computational cost which requires small AR and MA support sizes at the cost of diminished modeling effectiveness. However, in order to improve the modeling effectiveness, the support sizes can be increased in neural network based on ARMA models. Authors in [13] summarize the main properties of the spatial ARMA models and describe some of the well-known methods used in image filtering based on estimation of spatial autoregressive models. They also suggested a new filtering algorithm based on robust AR estimation. Authors of [14] addressed a new approach to the problem of improving the quality of remote-sensing images, by exploiting the idea of neural-network-based imaging system fusion. Because NN is easy to be trapped in local minima and converge too slow. The traditional training methods based on gradient searching technique are not effective and fast in determining accurate weights/biases of the neural network. In literature, various algorithms are proposed for training NN's, but most of them are derivative based and have some weaknesses such as converging to a local minima and time-consuming. Many global optimization methods have been used for this application such as genetic algorithm (GA) [15], particle swarm (PSO) [16], bacterial foraging (BFO) [17], and the differential evolution (DE) algorithm [18]. In paper [19], a GA is used to minimize the error performance surface in a NN based ARMA model with random Gaussian process is presented.

The Artificial Bee Colony algorithm is a swarm based meta-heuristic algorithm that was introduced by Karaboga in 2005 [20] for optimizing numerical problems. It was inspired by the intelligent foraging behavior of honey bees. The algorithm consists specifically of three essential components: employed and unemployed foraging bees, and food sources. The first two components, search for rich food sources, which is the third component, close to their hive. The Algorithm also defines two leading modes of behavior which are necessary for self-organizing and collective intelligence: recruitment of foragers to rich food sources resulting in positive feedback and abandonment of poor sources by foragers causing negative feedback. The ABC algorithm was first applied to numerical optimization [21]. Performance of the ABC algorithm was compared to those of the Genetic Algorithm (GA), Particle Swarm Inspired Evolutionary Algorithm (PS-EA) [22,23]; and to those of Differential Evolution (DE), PSO and Evolutionary Algorithm (EA) on a limited number of basic test problems [24,25]. The effect of region scaling on algorithms including ABC, DE and PSO algorithms was studied in [26]. The ABC algorithm was extended for constrained optimization problems in [27] and was applied to train neural networks [28,29], to medical pattern classification and clustering problems [30,31], to solve TSP problems [32]. Authors of [32] also studied the control mechanism of local optimal solution in order to improve the global search ability of the algorithm. Authors of [33] used the Artificial Bee Colony algorithm for the leaf-constrained minimum spanning tree (LCMST) problem called ABC-LCMST and compared the approach against GA, ACO and tabu search (TS). In [33], it is reported that ABC-LCMST outperforms the other approaches in terms of the best and average solution qualities and computational time. Authors in [34] applied the ABC algorithm to network reconfiguration problem in a radial distribution system in order to minimize the real power loss, improve voltage profile and balance feeder load subject to the radial network structure in which all loads must be energized. The results obtained by the ABC algorithm were better than the other methods compared in the study in terms of quality of the solution and computation efficiency. Finally, ABC was also used to train neural networks for pattern classification [35].

Traditionally image processing applications were implemented either in general-purpose Programmable Digital Signal Processors (DSPs) or built using Application Specific Integrated Circuit (ASIC) technology. Typically, Programmable DSP processors contain built-in Multiply/Accumulate units (MACs) and use a high level instruction set to implement image processing algorithms. Field-Programmable gate Array FPGA has become a very cost-effective means of off-load computationally intensive digital signal processing algorithms to improve overall system performance. They provide flexibility of software while keeping intact the hardware performances [36].

In this paper, the (ABC) algorithm is used to train a neural network to reach the global minimum and get optimized synaptic weights of an NN that models the ARMA representing both a better estimate image and near degradation function. Simulation results and performance assessment are presented. A statistical evaluation is realized with BID technique based on a range of current image quality metrics. BID takes further time to restore an image than a straight algorithm owing to the important computational load necessary to process images; therefore it is not appropriate to real-time applications. In this work, to speed up processing, the ARMA-NN model is implemented on a Xilinx reconfigurable FPGA chip via hardware description language: VHDL. This VHDL code is synthesized using ISE12.4 Xilinx software, simulated on the ModelSim 6.5 software for time and space constraints and next, experienced on the fast prototyping platform named ML505 based on a Virtex5-LXT FPGA chip of Xilinx. Hardware schemes and simulation results are presented in the final part of this article using ISE and ModelSim softwares.