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Edge preserving image enhancement via Harmony Search Algorithm

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Abstract— **Population based metaheuristic algorithms have been providing efficient solutions to the problems posed by various domains including image processing. In this contribution we address the problem of image enhancement with a specific focus on preserving the edges inherent in images with the aid of a musically inspired harmony search based metaheuristic algorithm. We demonstrate the significance of our proposed intuitive approach which combines efficient techniques from the image processing domain as well as from the optimization domain. Pertaining to the problem under consideration, further we compare our results with the state-of-the-art histogram equalization approach.**

Keywords-image enhancement; harmony search; metaheuristics; optimization; image entropy

I. INTRODUCTION

Research on enhancing images using digital image processing techniques has vital applications ranging from advanced space technology, medical diagnosis, machine vision based product assembly and inspection, biometrics, weather prediction based on satellite imagery and so on. In most of these applications, in order to get meaningful information from the raw images, certain image enhancement is often required. Many studies [1], [2], [3], [4] deploy some intelligent algorithms over the enhanced images rather than the raw images and hence image enhancement serves as a mandatory preprocessing stage in wide many computer vision techniques. Further, several recent studies [5], [6], [7] have shown that while enhancing images, preservation of edges are important in certain edge sensitive applications such as palm print analysis, image inpainting, analysis of microscopic images and so on. In this contribution, we intend to propose an image enhancement algorithm using the music inspired harmony search algorithm. We shall gradually show that our proposed approach is capable of preserving edges for a given raw image in the subsequent discussions to follow.

In general, image enhancement techniques can be broadly classified into two major categories namely, spatial domain approaches and frequency domain approaches [8]. The former one attempts to enhance raw images over the image plane whereas the later one is based on manipulating the Fourier transform of a given image. As our approach is based on the manipulation of pixels of the raw image, it can be conveniently classified as a spatial domain approach and as such we restrict the scope of this paper within the vicinity of the spatial domain.

II. RELATED WORK

In this section, we shall present some recent research relevant to our proposed approach from the imaging domain as well as from the harmony search based metaheuristic algorithms.

A. Spatial domain based image enhancement approaches

Celik and Tjahjadi [9] have very recently proposed an adaptive image enhancement algorithm based on a Gaussian Mixture Model (GMM) to enhance the contrast level of a given image. Using standard deviation as a control measure the authors compress or disperse the data entities. According to the authors, this mechanism enables to retain the grey-level distribution, thereby enhancing the contrast levels entailed in the image domain. The authors have illustrated that their method yields comparable results with other state-of-the-art image enhancement algorithms.

Arici and Dikbas [10] have proposed a content-adaptive contrast enhancement algorithm to enhance images. The authors have capitalized the idea that the normalized histogram of an image gives the approximate probability density function (PDF) of its pixel intensities. By manipulating the PDF the model can infer the probability that a pixel can hold a specific grey value in a given image. Further the objective of enhancing the images has been achieved by formulating the criteria as an optimization problem. One of the primary goals of the solution is to minimize the residual between the modified histogram, which is closer to an uniformly distributed histogram and the input histogram. In brief, the study deals with the fine tuning of several parameters that affect the histogram equalization process.

The fuzzy logic based bio-inspired approach proposed by Verma et al. [11] attempts to enhance highly dynamic color images by preserving the chromatic information entailed in them. The authors have applied the bio-inspired artificial ant colony system to optimize an intuitive objective function formulated by making use of Shannon entropy as well as visual appeal indicators. Further fuzzy logic has been used to tackle the uncertainty of whether a pixel should be made darker or brighter from its original intensity level for the sake

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of enhancement. Importantly as the naked human eye cannot quantitatively judge the level of contrast in an image and such visual assessment is subjective, the authors have resorted to fuzzy logic which is capable of associating a degree of belief to subtle image properties. The authors have compared their approach with their previous work based on a bacterial-foraging process and shown better results. Interestingly, optimization based approaches such as Genetic Algorithms and Particle Swarm Optimization (e.g. [12], [13]) have been contributing towards tackling the image enhancement problem.

B. Typical harmony search based approaches

As the proposed image enhancement approach in this contribution is based on *Harmony Search* (HS), we provide a brief overview about HS here and cite typical approaches that applies HS to solve some potential optimization problems. HS being invented by Geem et al. [14] in 2001, belongs to the family of metaheuristic optimization algorithms. In the real music domain, while composing a pleasant music, each musician tries to play the best piece of music with the goal of attaining an overall harmoneous music, over a series of practice sessions. Basically the harmony of the intended music gets improved by the mucisians over a series of practice sessions. Based on this musical inspiration Geem et al. formulated the HS algorithm which ultimately seeks a vector, which optimizes a certain objective function, over performing a series of iterations. One of the unique features which makes HS different from other metaheuristic based algorithms is that it iteratively explores the search space by combining multi-search space regions to visit a single search space region [15]. Recently, computer vision researchers (e.g. [16]) have been applying HS to address various problems in the imaging domain.

III. Modeling image enhancement via Harmony Search

In the image processing paradigm, the enhancement of a given input image I = f(x,y) is generally expressed using

$$g(x, y) = T[f(x, y)] \tag{1}$$

where g(x,y) is the output image obtained by enhancing f(x,y) with the aid of an operator T, defined over a pre-defined neighborhood of (x,y). As suggested by typical optimization based image enhancement techniques [12], [13], our proposed model relies on the following transformation

$$g(x, y) = \left(K \frac{M}{\sigma(x, y) + b}\right)[f(x, y) - c * m(x, y)] + m(x, y)^a \tag{2}$$

where m(x,y) and (x,y) are the gray-level mean and standard deviation computed in a neighborhood centered at (x,y) and typically having 3*3 pixels, M is the global mean of the image, f(x,y) is the gray-level intensity of the input image pixel at location (x,y). Further the key parameters a,b,c and k used in eq. (2) which remain as constants while processing the whole image, contributes significantly to the image enhancement process. In other words, T(I) would logically represent the transformed image obtained using eq. (2) with the impact of these key parameters. Hence, our proposed approach aims to optimize these key parameters using a Harmony search based algorithm. To estimate how well a set of candidate solutions represented by these key parameters enhance a given image, we make use of the following objective function (fitness measure) formulated by Munteanu and Rosa [12]

$$Obj(H) = \log\left(\log\left(\xi(H[T(I)])\right)\right)\left(\frac{\Xi(T[I])}{H_x \times V_x}\right)\Omega(T[I])$$

where *Obj(H)* measures the fitness of a candidate solution represented by the vector {a b c k}, *T(I)* represent the transformed image *I* with the aid of eq. (2), is a measure of the intensity of the edges detected using a Sobel edge detector [17] and is a measure of the number of pixels in the edges, i.e. edgels, which are usually detected by deploying a Sobel edge detector function. Further the measure of the entropy of the transformed image is represented by Ω(T[I]); respectively represent the number of pixels in the horizontal and vertical direction of the image under consideration. In the imaging domain, it is a common practice to use entropy in order to get a statistical measure of randomness that can be in turn used to characterize the information content of a given image. It has been empirically observed that, during the iterations of the proposed Harmony search by maximizing the candidate solution in turn tries to achieve the following objectives:

- Boost the relative number of edges in the image
- Enhance the overall intensity of edges
- Improve the entropic measure in the image.

Thus the proposed technique could be considered to be feasible in preserving edges that are inherent in an image using the above described formulation.

Further we shall brief down the various processes involved in the proposed framework using the flowchart shown in Fig.1. Firstly the algorithm initializes the HS parameters namely, the Harmony Memory Consideration Rate (HMCR), the Harmony Memory Size (HMS), the Pitch Adjustment Rate (PAR) and the maximum number of improvisations upon which the number of iterations terminates. Similar to how a genetic algorithm stores a set of candidate solutions in proportion to the population size, the HS in order to store the candidate solutions, initially allocates what is called as a Harmony Memory (HM) which is represented by

$$HM = \begin{pmatrix} x_1^1 & x_2^1 & \cdots & x_N^1 & | & f(x^1) \\ x_1^2 & x_2^2 & \cdots & x_N^2 & | & f(x^2) \\ \vdots & \vdots & \ddots & \vdots & | & \vdots \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_N^{HMS} & | & f(x^{HMS}) \end{pmatrix} \tag{4}$$

After the initialization of HS parameters, the input image is read and several image statistics as mentioned in the flowchart are computed, before the start of the iterative process.

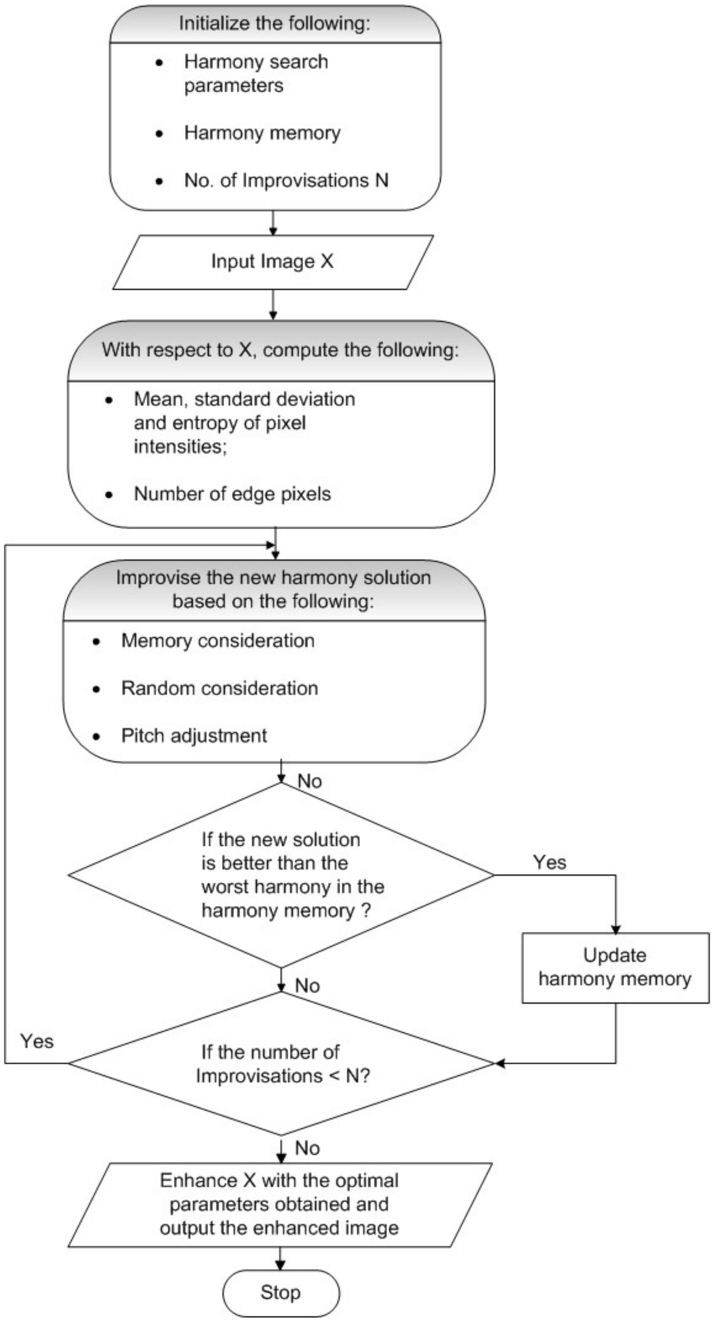

Figure 1. Flow chart of the proposed image enhancement model based on harmony search

Then for each iteration until the stopping criteria is met, i.e. until the number of improvisations is reached, a new solution vector is generated based on three operators namely memory consideration, random consideration and pitch adjustment. Memory consideration aids to exploit the solution space from the historical values stored in the HM vectors.

Random consideration enables random assignment of values to candidate solutions for values that are not fetched by memory consideration. In fact, memory consideration and random consideration can be functionally similar to the recombination and mutation operators that are deployed in genetic algorithms.

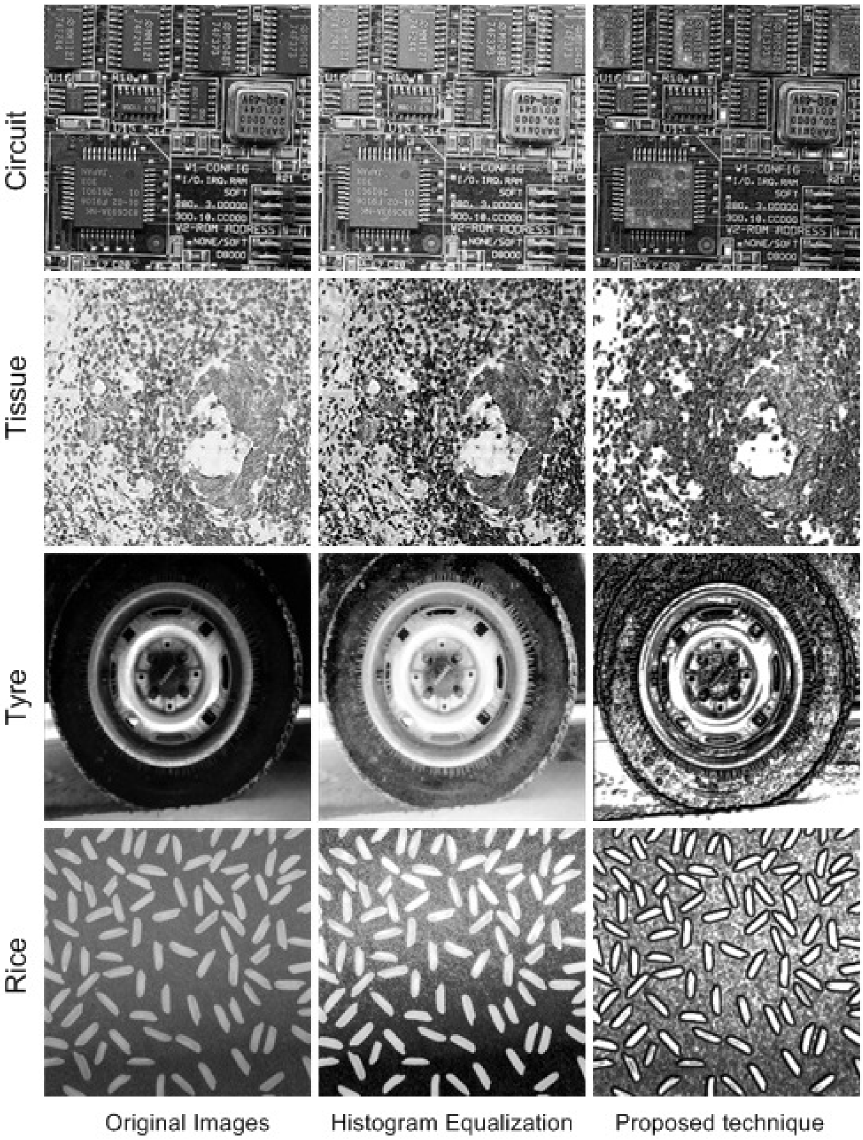

Figure 2. Results of experimental simulations; The enhanced image yielded by the proposed algorithm has been compared with the original image as well with the conventional histogram equalization technique.

Depending on the probability of PAR, each decision variable will be determined to whether or not to undergo a pitch adjustment. Then in terms of the fitness perspective, if the new solution is found to be superior than the worst harmony solution stored in the HM, the new solution is appended to the HM and the worst solution is removed from the HM. The iterations are carried out until the stop criterion is met. Ultimately, after the completion of the iteration phase, using the best candidate solution set obtained (optimal parameters), the input image is enhanced which is basically the output image yielded by the proposed HS based image enhancement algorithm.

IV. Empirical Evaluation Of The Proposed Algorithm

We have implemented the proposed image enhancement algorithm using the MATLAB programming environment. For our experimental purpose, we have chosen four typical images namely, a circuit board, microscopic view of a tissue segment, a tire and some rice grains. We have used the maximum number of iterations allowed in the Harmony Search to be 200 and the combination of the parameters used for our experiments are HMS: 100, PAR: 0.6 and HMCR: 0.9.

A comparison of the original image with that of the enhanced images yielded by the conventional histogram equalization (HE) algorithm and the proposed music inspired harmony search algorithm (HS) is coherently shown in Fig. 2. The assessment of image enhancement with the aid of naked human eyes is very subjective, especially in gauging the image content in terms of preserved edges inherent in the images. Hence as suggested by image enhancement studies [12], [13], we have used the number of edgels inherent in the images as a measure of quality of image content. This potential evaluation criterion also complies to our objective, which is enhancing the images by preserving the edges inherent in the images.

TABLE I. EVALUATION OF QUALITY OF IMAGE CONTENT IN TERMS OF NUMBER OF EDGELS FOR THE TYPICAL IMAGES CHOSEN FOR EXPERIMENTAL PURPOSE.

Image	**Number of edges**		
	Original	***Hist Eq.***	***HS***
Circuit	7375	7375	8141
Tissue	4686	4737	4816
Tire	3158	3693	3999
Rice	9549	5979	7277

The results of number of edges with respective to each of the four images taken into account for our experiments are tabulated in Table I. For the circuit board image, while HE is unable to enhance the original image any further, the proposed HS algorithm is able to enhance it by about 10%. For the case of the Tissue image, HE and HS has respectively yielded an enhancement of about 1% and 3%; with that of the Tire image, this is achieved as 17% and 27 %. But for the image which contains some rice grains, neither the HE and nor the HS were able to enhance the image. This could be possibly due to more background present in the image than the rice grains. Overall, we see that the proposed HS based algorithm seems to be better in preserving the edges than the conventional HE oriented image enhancement algorithm.

IV. CONCLUSION AND FUTURE WORK

In this contribution, we have presented an intuitive musically inspired harmony search algorithm to enhance the images by preserving the edges by adapting techniques both from the image processing domain as well as from the optimization domain. We have compared the effectiveness of our approach with the state-of-the-art histogram equalization (HE) technique. Our results using some standard preliminary experiments show that the proposed algorithm shows some appreciable improvement over the conventional HE algorithm. To the best of the knowledge of the authors, this contribution is a pioneering and intuitive effort to deploy a musically inspired approach towards an image enhancement problem. In the near future we would like to explore more on the behavioral aspect of the HS algorithm with respect to more advanced image processing algorithms.

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