

Hybrid Swarm Optimization for Document Image Binarization Based on Otsu Function

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Abstract

The Binarization of the historical documents is NP-hard problem since the image contains noise, source degradations, and illumination. The aim of binarization is to find the proper image pixels' threshold to improve the overall performance of the system. This paper introduces a new hybrid meta-heuristic algorithm to determine the best threshold value for image documents binarization. This hybrid based on the Artificial Bee Colony (ABC) and the Firefly Algorithm (FA), and it is called ABCFA. It is making the two algorithms searching about the best threshold, which maximizes the Otsu function in simultaneous with half of the population for each algorithm. Therefore, this type of hybridization avoids the drawbacks of other hybrid methods. The results of applied the ABCFA on DIBCO13 dataset show a better accuracy than the other binarization methods such as Otsu and Niblack.

Keywords: image processing, document image binarization, meta-heuristic

1. Introduction

Across the world, a huge number of document images and historically manuscripts need to preservation and digitization. Owing to, aging and physical conditions, these old manuscripts, and documents are usually severely degraded [1]. Although various models and methods have been developed to achieve this goal, the binarization of historical documents is an essential requirement in the preprocessing and enhancement stages for the document image analysis and retrieval. At the same time, effective binarization can be used to reprocess and enhance the degraded images to achieve better legibility [2]. Throughout the literature, there are many advanced binarization methods, which can be broadly categorized into two groups; global and local methods depending on how threshold value is calculated for the image to be segmented

[1],[2]. The global approach gives satisfying results when the pixels in each class are close to each other. The leading and pioneering work on global threshold based methods is Otsu's method[3]. Which applied a single threshold value to minimize intra-class variance by assuming that the image contains two classes of pixels. This approach gives satisfying results when the pixels in each class are close to each other. However, Otsu cannot efficiently handle documents with degradations such as bleed-through, faint characters or uneven background. On the other hand, for a local method [4], a number of threshold values can be calculated for different regions of an image depending on some properties of the image. Some of these are Niblack, Sauvola, Bernsen and Mean threshold methods. For instance, Niblack's method used mean value and variance of a small window to determine the threshold of centered pixels. The limitation of this method is that a large amount of noises is produced in pure blank background areas and it is sensitive to the window size. Sauvola modified the Niblack threshold to reduce the background noise, but the text detection rate is also decreased while bleed-through remains in most cases[5].

Recently, machine learning is not only important for classification and clustering applications, but also in improving the performance of binarization methods. For example, in [6] the Genetic Algorithm (GA) is used to determine the best threshold to binarize the strip steel image, then used to determine the defect in the images. However, the genetic algorithm suffers from premature convergence and stuck in local point. To avoid these problems, this paper provides a new hybrid swarm algorithm based on the Artificial Bee Colony (ABC) and Firefly algorithm (FA). In general, the ABC has simulated the behavior of honey bees' colony [7], and the FA simulate the flashing lights of fireflies. Based on more studies [8-11], that applied the two algorithms to many applications; our motivation is to

improve the performance of the two algorithms to find the best threshold through combining them. Moreover, the proposed algorithm (ABCFA) avoids the problem in other hybrid methods by dividing the population into two sub-populations (half the size) assigned for each one. Each algorithm used its strategy to update its population in parallel then the best solution from the two sub-populations is selected. Therefore, the time complexity of other hybrid algorithm is avoided in ABCFA.

The rest of the paper is organized as the following: In Section 2, the preliminaries of binarization, ABC, and FA are introduced. Section 3 illustrates the proposed algorithm, in section 4, the experimental results of the proposed algorithm are discussed. Finally, the conclusion and the future works are given in section 5.

2. Preliminaries

2.1 Problem Formulation

The Binarization problem can be defined as the process of determining the threshold t which split the image I into two groups. The first group is the pixels less than t otherwise it, is the second group, therefore, a binary image is obtained. Consider I is represented by L gray levels, [11] binarization threshold is defined as:

$$G_0 = \{g(x, y) \in I | 0 \leq g(x, y) \leq t - 1\} \quad (1)$$

$$G_1 = \{g(x, y) \in I | t \leq g(x, y) \leq L - 1\}$$

2.2 Otsu Function

The Otsu function is used to determine the best threshold which maximizes the variance between the different image groups. It is defined as [11]:

$$f(t) = \sigma_0(\mu_0 - \mu_T)^2 + \sigma_1(\mu_1 - \mu_T)^2 \quad (2)$$

$$\mu_0 = \sum_{i=0}^{t-1} \frac{ip_i}{\sigma_0}, \mu_1 = \sum_{i=t}^{L-1} \frac{ip_i}{\sigma_1}, p_i = \frac{h_i}{\sum_{i=0}^{L-1} h_i}$$

Where μ_T and h_i represent the mean intensity of I and frequency of the gray level i .

The best threshold is determined by using:

$$t^* = \arg \max(f(t)) \quad (3)$$

2.3 Artificial Bee Colony (ABC)

Following [8], the ABC algorithm has three groups of bees which work together for searching about the foods; these groups are the employed, onlooker and the scout bees. The steps of the ABC starts by a random population X of size N where each individual of this population represents a solution $x_i =$

$1, 2, \dots, N$. The employee bees generate a new solution v_i by using x_i and its a neighbor bee x_k as in equation (1) [8]:

$$v_{ij} = x_{ij} + \zeta(x_{ij} - x_{kj}), k = \text{int}(\omega \times N) \quad (4)$$

Where ζ and ω are a random value. The new solution v_i is compared with the x_i to decided to what saved in memory and removed, this performed based on the comparison between the fitness function of two solutions ($f(v_i)$ and $f(x_i)$), where the best is save and the smallest is removed.

The onlooker receive the value of the fitness functions from employed bees and then the x_i which has the higher probability of fitness function x_i is selected by using the roulette wheel selection mechanism. The P_i is defined as:

$$P_i = \frac{fit_i}{\sum_{i=1}^N fit_i}, fit_i = \begin{cases} \frac{f_i}{1+f_i} & f_i > 0 \\ 1 + |f_i| & otherwise \end{cases} \quad (5)$$

The onlooker bees used the same strategy of employed bees to update their solutions. However, after a limited number of iterations, if the solutions of onlooker bees not improved, then they are replaced by new random solutions which generated by the scout bee group (and it considered as employed bee solution) as in the following equation:

$$x_i = x_i^{min} + (x_i^{max} - x_i^{min})\delta \quad (6)$$

Where x_i^{max} , x_i^{min} and δ represent the upper, lower bounds for the solution x_i , and a random number respectively. The pseudocode of ABC is given in [7].

2.4 Firefly Algorithm (FA)

FA is introduced in [11], where the brightness and attractiveness of the fireflies are updated during the time. The attractiveness (η) between the pairs i and j of fireflies is defined as:

$$\eta = \eta_0 e^{-(\gamma sd_{ij}^2)}, sd_{ij} = \sqrt{\sum_{k=1}^D (y_{ik} - y_{jk})^2} \quad (7)$$

Where $\eta_0 = 1$ and γ represent the attractiveness and the coefficient of the light absorption, respectively. y_{ik} is the k th component of the spatial coordinate y_i of i th firefly. The process of movement the firefly y_i to a higher attractive firefly y_j is defined as:

$$y_i = y_i + \eta(y_i - y_j) + \beta \varepsilon_i \quad (8)$$

where $\beta \in [0, 1]$ and $\varepsilon_i \in N(\mu, \sigma)$ represent a random number and a random vector,

respectively. The pseudocode of FA is given in [11].

3. The Proposed Algorithm

The aim of the proposed algorithm (ABCFA) is to determine the best threshold value which maximizes the Otsu's function described above. ABCFA starts by computing the histogram of the input image and generating a random population (solutions of the threshold value) of size N . Then, this population divide into two half($N/2$), X_{ABC} and X_{FA} which assigned as population of ABC and FA, respectively. At the same time the solutions in the X_{ABC} and X_{FA} are updated based on the ABC and FA algorithms, respectively, as discuss in the previous section. From the division process, the two algorithms searching the solution space at the same time, which avoid the time complexity in the other hybrid algorithms as in the hybrid between Firefly and social-spider optimization (FASSO) [12]. Next, the best global solution x_{best} and its corresponding fitness function f_{best} (which maximize Equation (3)) are determined from X_{FA} and X_{ABC} . All the previous steps of the ABCFA algorithm are repeated until the stopping conditions are satisfied. The image is converted to binary based on x_{best} and the performance of the binary image is evaluated. The final algorithm is illustrated in Figure 1.

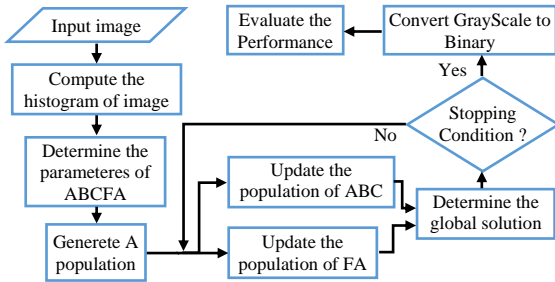


Figure 1: The proposed algorithm for Image Binarization.

4. Experiments

The performance of the proposed method is testing on the DIBCO13 (Document Image Binarization Contest 2013) series datasets which include a variety of degraded handwritten document images [3]. Sample images from the dataset and ground truth

image are given in Figure 2. The proposed method compared with other seven algorithms, one of them is a global thresholding Otsu, four are a local thresholding Niblack, Sauvola, Bernsen and Mean Threshold (MT) and last two are swarm algorithms (GA [6], and FASSO [12]).

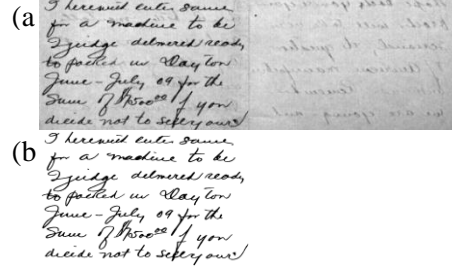


Figure 2: (a) Sample of Historical Images (b) Ground truth image.

To assess the accuracy, we use visual appearance and direct evaluation, in terms of; F-measure ($F-m$), Geometric accuracy (Gac), Peak Signal-to-Noise Ratio ($PSNR$), Negative metric rate (NRM), Distance reciprocal distortion (DRD) metric, Sensitivity (Sen) and Misclassification penalty metric (MPM) [5]. The comparison results between the proposed algorithm and the other algorithms are given in Table 1. From this table, the proposed algorithm give higher values for the $F-m$, Gac , and $PSNR$ than other algorithms. At the same time, regarding NRM , the ABCFA is better all algorithms except both algorithms Otsu and the MT which have nearly the same result 0.08 but this difference not significant. Based on the value of DRD , the better algorithm is the Sauvola method, and MT is in the second rank, whereas, the proposed algorithm fourth position which gives smaller value than the rest algorithms. As well as, the proposed method provides the higher sensitivity value than other algorithms which indicates that, the ABCFA can classify the objects (text) in the image with high performance. In the last measure, MPM , the best algorithm is Sauvola with 0.0008 value, while in the second rank the ABCFA comes with 0.0117.

Table 1: The Comparison results for Binarization.

	$F-m$	Gac	$PSNR$	NRM	DRD	MPM	Sen
Otsu	72.27	0.91	14.28	0.08	7.67	0.0190	0.902
Niblack	28.82	0.76	4.93	0.23	65.41	0.1931	0.545
Sauvola	14.28	0.72	15.23	0.23	3.06	0.0008	0.874
Bernsen	55.95	0.90	10.27	0.10	22.07	0.0509	0.824
MT	74.49	0.92	14.52	0.08	6.67	0.0124	0.910
GA	48.22	0.63	12.30	0.25	10.06	0.0308	0.879
FASSO	70.08	0.90	13.89	0.09	8.51	0.0200	0.534
ABCFA	81.61	0.92	15.40	0.09	7.12	0.0117	0.912

5. Conclusion

In this paper, a new hybrid swarm algorithm is proposed to improve the binarization of document image through determining the best threshold value which separates the image into two components the text and the background. Our method avoids the complexity of other hybrid swarm methods through making the ABC and FA work together in the same domain yet in a parallel environment. The results reveal that the ABCFA is powerful binarization method, which improves the quality of binarized image through reducing the noise. In the future work, we will focus on developing our method to work in the multi-level thresholding segmentation.

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