A Hybrid of Fireworks and Harmony Search Algorithm for Multilevel Image Thresholding

Shivali, Lalit Maurya, Ekta Sharma, Prasant Mahapatra and Amit Doegar

Abstract Multilevel image thresholding is an essential part of image processing. This paper presents a hybrid implementation of fireworks and harmony search algorithm where Kapur's entropy is used as the fitness function for solving the problem. The results of the proposed method have been compared with the standard fireworks algorithm (FWA) and particle swarm optimization (PSO) based multi-level thresholding methods. Experimental results indicate that the proposed method is a promising approach in the field of image segmentation.

Keywords Image segmentation · Multilevel image thresholding · Fireworks algorithm · Harmony search algorithm · Kapur's entropy

1 Introduction

Image segmentation based on multilevel thresholding technique is an intriguing and critical task. There are various techniques for image segmentation, out of which thresholding is the one largely used because of its easy implementation. Partitioning

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R.K. Choudhary et al. (eds.), *Advanced Computing and Communication Technologies*, Advances in Intelligent Systems and Computing 562, https://doi.org/10.1007/978-981-10-4603-2_2

the original image into various numbers of classes for extraction of meaningful information [1] is defined as image thresholding. If the image is segmented in two classes namely the foreground and the background, it is termed as bi-level thresholding. The concept can further be extended to multilevel thresholding for attaining more than two classes [2].

However, it necessitates an optimal value of threshold to separate foreground from their background. The main aim of thresholding is to select best value of threshold [1]. Till date, numerous methods for thresholding have been developed. A criterion called Otsu criteria [3] was proposed which maximizes between class variance for getting segmented regions of the image. Moment preserving approach was used by Tsai [4] for selecting threshold of grayscale images, which is referred to as Tsallis entropy. Kapur et al. [5] used entropy of the histogram for thresholding. According to Kapur's criterion, entropy of each class or sum of entropies was maximized based on information theory.

Throughout the years, many heuristic algorithms including genetic algorithm [6], particle swarm optimization [7], firefly algorithm [8], bacterial foraging algorithm [9], ant colony optimization [10], harmony search algorithm [11], cuckoo search algorithm [12] and fireworks algorithm [13] have been used for image thresholding. In this paper, to find the optimal value of threshold for image segmentation, fireworks algorithm is hybridized with harmony search algorithm and Kapur's entropy is used as fitness function.

The remaining part of the paper is structured as follows: Sect. 2 gives introduction to fireworks algorithm, Sect. 3 gives introduction to harmony search algorithm. Proposed methodology is outlined in Sect. 4. The experimental results are shown in Sect. 5. The conclusions are drawn in Sect. 6.

2 Fireworks Algorithm (FWA)

```
Select random n locations for fireworks
while maximum function evaluations is not reached do
Set off n fireworks at n locations
for each firework x_i do
Calculate the number of sparks S_i and amplitude for fire-
work A_i
Obtain locations of S_i sparks of firework x_i
end for
for k = 1 : number of Gaussian sparks do
Select random firework x_j
Generate a Gaussian spark for selected firework
end for
```

```
Select best firework for next iteration
Select randomly n − 1 from two types of sparks and fire-
works based on probability
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end while

FWA has two types of fireworks: well-manufactured firework and lower quality firework. It has four parts: explosion operator, mutation operator, mapping strategy and selection strategy [14]. Explosion operator generates sparks around the fireworks. Mutation operator governs the number and the amplitude of sparks.

3 Harmony Search Algorithm (HSA)

In HSA [15], every solution is known as harmony which is denoted by n-dimensional real vector. First, an initial population of harmony vectors is generated arbitrarily and is kept in the harmony memory (HM). A new candidate of harmony is produced using either pitch adjustment operation or random re-initialization from the elements in HM. Finally, HM gets updated by comparison of new harmony and worst harmony. The above process keeps on repeating itself until the stopping criterion fulfills.

4 Proposed Methodology

In general, the multilevel thresholding based on the optimization algorithm uses the objective function which has to maximize by the optimization algorithm. In this work, Kapur's method is used to define the objective function for the thresholding and the proposed hybrid algorithm has to find out the threshold level by considering Kapur's method.

4.1 Kapur's Entropy Function

Kapur's entropy is used in this paper for image thresholding and is formulated as follows [13]:

Let an image I contains n number of pixels whose gray level lies between 0 and $L-1$. Let h_i denote the number of pixels at gray level i, and the likelihood of occurrence of gray level i in the image is denoted by pr_i as shown in Eq. (1)

$$\mathrm{pr}_i = h_i/n, \tag{1}$$

where the k dimensional problem is a division of an image into $k + 1$ classes and obtaining k optimal thresholds (t_0, t_1, … t_{k-1}). The objective function as mentioned in the Eq. (2) is maximized, and hence the optimal value of threshold is obtained.

$$f\,(t_0,\, t_1 \ldots t_{k-1}) = \sum_{i=0}^{k} H_i \tag{2}$$

where, entropies H_i is defined as:

$$H_0 = -\sum_{i=0}^{t_0-1} \frac{\mathrm{pr}_i}{w_0} \ln \frac{\mathrm{pr}_i}{w_0}, \quad w_0 = \sum_{i=0}^{t_0-1} \mathrm{pr}_i \tag{3}$$

$$H_1 = -\sum_{i=t_0}^{t_1-1} \frac{\mathrm{pr}_i}{w_1} \ln \frac{\mathrm{pr}_i}{w_1}, \quad w_1 = \sum_{i=t_0}^{t_1-1} \mathrm{pr}_i \tag{4}$$

$$H_k = -\sum_{i=t_{k-1}}^{L-1} \frac{\mathrm{pr}_i}{w_k} \ln \frac{\mathrm{pr}_i}{w_k}, \quad w_k = \sum_{i=t_{k-1}}^{L-1} \mathrm{pr}_i \tag{5}$$

The threshold at which function returns maximum value is considered as the optimal value of threshold.

4.2 Proposed Hybrid Algorithm: FWA/HSA

In standard FWA, the fireworks with better objective value generate a larger explosion sparks within range (within small explosion amplitude). Conversely, fireworks with low objective value generate a smaller explosion spark within a smaller range. These characteristics allow balancing the exploration (diversification) and exploitation (intensification). However, it has been found that FWA shows a premature convergence for the function which does not have their optimum at the origin. In this work, the standard FWA convergence behavior is improved by introducing harmony search algorithm for the multilevel thresholding problem. The harmony search algorithm provides a better balance of intensification and diversification. In proposed hybrid method diversification is better controlled by the pitch adjustment and random selection.

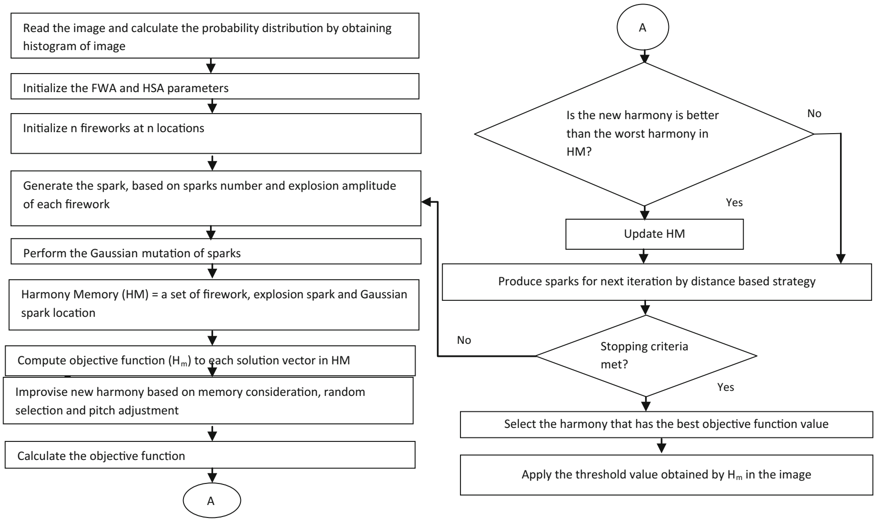

Fig. 1 Flow chart of proposed algorithm

In the proposed hybrid method, at each iteration FWA produces a set (called as seedmatrix) of firework, explosion spark and Gaussian spark location. The HM corresponds to the each particle generated by FWA, i.e., all solutions of FWA stored in the HM. After that the harmony search operation, namely memory consideration, random selection and pitch adjustment operator are performed on the set of firework, explosion spark and Gaussian spark location. If the new harmony obtained after the harmony operation is better than the worst harmony, it is replaced by the worst harmony in HM. Therefore, introduction of harmony search operation improves the diversity of the standard FWA. It increases the speed of global convergence and reduces the chances of stuck in local optima. At each iteration, the distance-based strategy is used to select the best spark from seedmatrix as a firework of the next iteration. The flow chart of the proposed hybrid algorithm for multilevel thresholding has been shown in Fig. 1.

5 Experimental Results

The proposed hybrid algorithm FWA/HSA has been applied to some standard test images and lathe tool's images. The reason for using lathe tool's images is that the authors used the tool to carry out different experiments on micro and nano scale movements for desktop machining [16]. The proposed method has been tested on

Table 1 Simulation results of proposed hybrid algorithm

Image	K^a	Threshold values	Objective function
Pirate	1	102	13.0784
	2	89, 170	18.1847
	3	59, 114, 171	22.7723
	4	48, 89, 131, 173	26.9231
Clock	1	134	12.7189
	2	32, 131	17.7190
	3	32, 102, 168	22.5607
	4	32, 91, 144, 197	27.0509
Elaine	1	151	12.9879
	2	107, 175	17.9454
	3	91, 143, 193	22.3877
	4	22, 93, 148, 198	26.8252
Home	1	117	13.3231
	2	83, 168	18.5773
	3	65, 125, 186	23.2543
	4	55, 107, 159, 204	27.5938
Ref	1	23	9.4304
	2	20, 82	14.1644
	3	26, 145, 166	19.6226
	4	20, 83, 145, 166	24.2756
Move 2mm	1	21	9.4042
	2	20, 84	14.2457
	3	27, 146, 166	19.6351
	4	19, 82, 146, 165	24.2693
Move 4mm	1	24	9.3409
	2	21, 82	14.1449
	3	23, 144, 164	19.5968
	4	24, 144, 164, 209	24.0126

[a] *K* is the level of segmentation

all the images available in [17] but here only four images have been shown. The parameters set for hybrid algorithm are number of fireworks—5, highest value of explosion amplitude Â—40, Spark number coefficient (*m*)—50, HMCR—0.95, PAR—0.5, BW—0.5. The stopping criterion is selected as a number of iteration in which best fitness remains constant at 10% of the number of iterations (NI) or max number of iterations is achieved. Table 1 shows the results of the proposed hybrid algorithm. Figure 2 shows the segmented result of selected images with

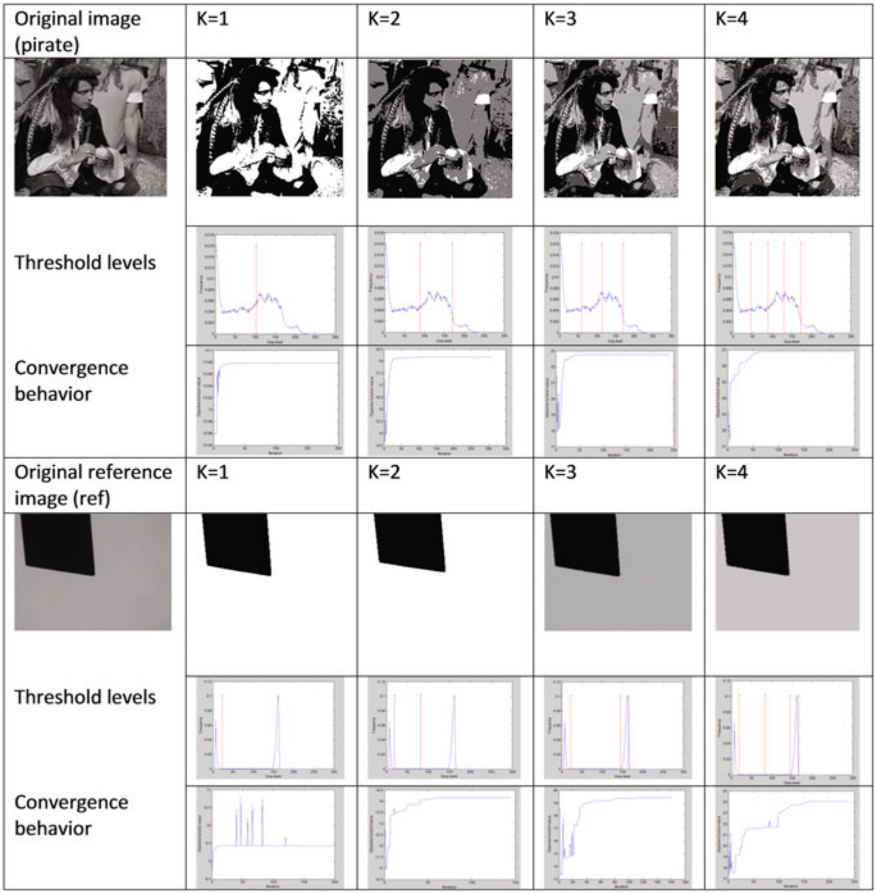

Fig. 2 Segmented result of selected image with threshold level and convergence behavior

convergence behavior and threshold level. In Table 2, the proposed hybrid algorithm has been compared with the PSO and standard FWA based multilevel thresholding. The algorithm is run 25 times for each value of k over each image. For each image, mean objective function value, standard deviation, and computation time are calculated. Table 2 shows that the hybrid algorithm based method's mean values of objective functions over 25 runs are superior to other methods. The computational time of proposed hybrid FWA/HSA based multilevel thresholding method is less than PSO and standard FWA based method because it shows better and fast convergence behavior and mostly converge before the max number of iterations. It has been observed that the proposed algorithm is superior to the other algorithm and give excellent solution. It has also been observed that the proposed algorithm gives superior result in terms of computational time because it shows the fast convergence behavior.

Table 2 Standard deviation and computation time of PSO, standard FWA and proposed method

Image	K	PSO			FWA			Proposed hybrid FWA/HSA		
		Mean	Standard deviation	Time (s)	Mean	Standard deviation	Time (s)	Mean	Standard deviation	Time (s)
Pirate	2	13.0783	1.2796e−04	10.0503	18.060	0.6205	10.0882	18.0528	7.0030e−05	3.2112
	3	18.1498	0.0385	14.5952	21.3125	1.0206	10.9682	21.4766	0.0739	8.0042
	4	22.5628	0.2023	11.2853	25.7642	1.3337	14.0045	26.2171	0.0443	7.5213
	5	26.1371	0.4543	14.8767	29.9721	1.5348	14.8596	30.4197	0.2130	11.1767
Clock	2	12.7189	3.1171e−04	10.4248	17.3671	0.8162	12.1728	17.2433	0.0741	4.2243
	3	17.5770	0.0947	14.0783	21.2537	1.1931	12.0240	21.2702	0.2073	9.3374
	4	22.0902	0.6433	15.1192	25.3670	0.9401	13.1073	25.5546	0.6213	11.1652
	5	25.5236	1.6407	15.7067	29.3215	1.1934	13.3215	29.7579	1.0752	9.1358
Elaine	2	15.3425	0.0078	10.4651	17.9453	4.3660e−05	10.7238	17.8265	0.0039	4.7315
	3	17.8932	0.5821	14.8290	21.2731	0.9585	11.2731	21.7786	0.9122	6.5900
	4	23.5471	1.0452	14.0281	25.9743	0.3778	11.9915	25.9511	0.4017	8.4311
	5	25.5047	1.4024	14.7398	30.6002	0.8375	12.5938	30.4646	0.9885	7.9989
Home	2	13.3108	0.4714	10.8322	18.4387	0.6866	10.1472	18.4358	0.6768	8.9142
	3	18.4232	1.3221	11.2887	21.9726	1.1585	10.9291	21.9617	1.1493	9.4964
	4	22.5021	1.2023	14.0121	26.5845	0.8698	11.7494	26.5678	0.9389	8.5269
	5	26.2171	1.9231	14.8943	30.9394	1.7066	12.3634	30.9736	1.6124	7.6879
Reference	2	13.5671	0.6781	10.0361	14.5422	0.514102	10.3304	14.4477	0.4671	5.1242
	3	17.1292	1.8391	15.0283	18.7125	1.2052	11.2437	18.5380	1.3870	7.6134
	4	20.0831	1.4568	14.0289	22.0982	1.5032	11.8846	22.0189	1.4425	10.2289
	5	23.8093	1.9563	14.9210	25.9076	1.5498	12.9770	25.3118	1.0948	11.0628

(continued)

Table 2 (continued)

Image	K	PSO			FWA			Proposed hybrid FWA/HSA		
		Mean	Standard deviation	Time (s)	Mean	Standard deviation	Time (s)	Mean	Standard deviation	Time (s)
Move 2 mm	2	13.0567	0.5309	9.9312	14.3621	0.4489	10.3205	14.8227	0.5231	5.4890
	3	17.2034	1.0382	10.9283	18.4290	1.6082	12.3891	18.3221	1.6455	9.4725
	4	20.1139	1.2389	14.8292	22.1380	1.5138	13.6345	22.4343	1.4345	10.8052
	5	23.8930	1.5930	14.9723	26.0206	1.9142	14.6207	25.0626	1.3318	14.2404
Move 4 mm	2	13.0562	0.4821	10.0231	14.5530	0.5797	12.7458	14.3539	0.4824	5.9210
	3	17.2730	1.3820	14.8293	18.1527	1.8324	13.5795	18.5650	1.2327	8.4001
	4	20.4511	0.9322	14.7282	22.4778	1.9145	14.5243	21.9931	1.3823	13.4602
	5	23.8948	1.5920	14.9212	25.3100	1.2854	13.7559	25.4694	1.2320	12.1681

6 Conclusion

In this paper, a hybrid of standard fireworks algorithm (FWA) and harmony search algorithm (HSA) based multilevel thresholding has been proposed. In proposed hybrid algorithm, the fireworks algorithm has been improved by introducing harmony search operations, viz., memory consideration, random selection, and pitch adjustment operator. Introduction of harmony search operation improves the diversity of the standard FWA. It increases the speed of global convergence and reduces chances of getting trapped in local optima. In the standard FWA, the initial best value is selected for next iteration and remaining $n - 1$ values are selected on the basis of distance-based strategy. In the proposed technique, harmony search operations are performed on the matrix which contains initial fireworks, explosion sparks, Gaussian sparks. Then, old matrix is compared to the new one and the best values among both are kept in the new matrix. Then, best firework from the new matrix is selected to be passed to the next iteration and remaining $n - 1$ fireworks are selected as per the procedure of the standard FWA. This improves the time complexity (optimum value is reached in less time) and also reduces the chance to get trapped in local optima solutions.

Particle swarm optimization (PSO) has been widely used for image thresholding recently, hence, the proposed algorithm has been compared to PSO and in that case also the proposed method is found to be superior.

Acknowledgements This work is supported by the Council of Scientific and Industrial Research (CSIR, India), New Delhi under the Network program (ESC-112) in collaboration with CSIR–CMERI, Durgapur. Authors would like to thank Director, CSIR–CSIO for his guidance during the investigation.

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http://www.springer.com/978-981-10-4602-5

Advanced Computing and Communication Technologies
Proceedings of the 10th ICACCT, 2016
Choudhary, R.K.; Mandal, J.K.; Bhattacharyya, D. (Eds.)
2018, XXIV, 336 p. 117 illus., Softcover
ISBN: 978-981-10-4602-5