A MULTI-LEVEL THRESHOLDING IMAGE SEGMENTATION USING NATURE-INSPIRED OPTIMIZATION ALGORITHMS

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AGENDA

- Introduction to Image Thresholding

1 ✓

- Application of Multi-level thresholding based on Metaheuristics in literature

2 ✓

- Proposed Models

3 ✓

- Open Issues

4 ✓

- Conclusion

5 ✓

IMAGE SEGMENTATION

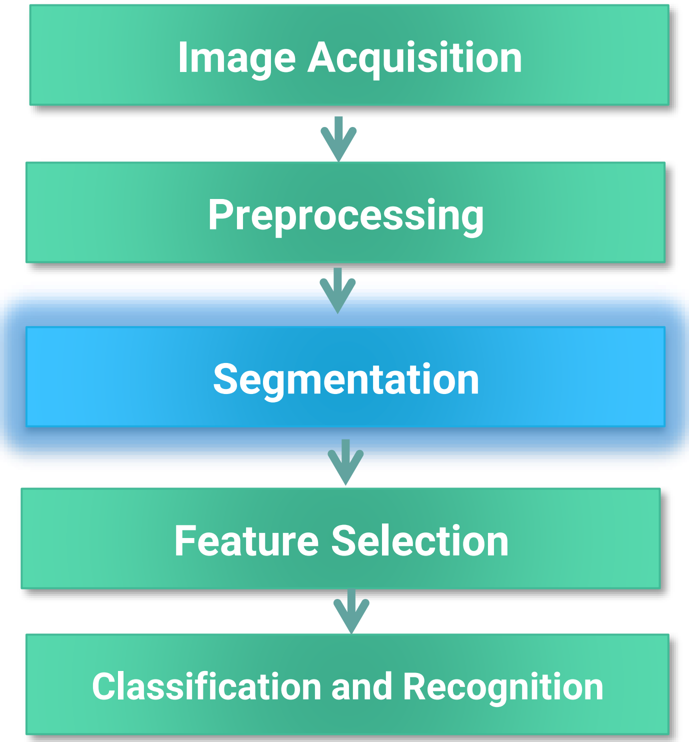


Image Acquisition

Preprocessing

Segmentation

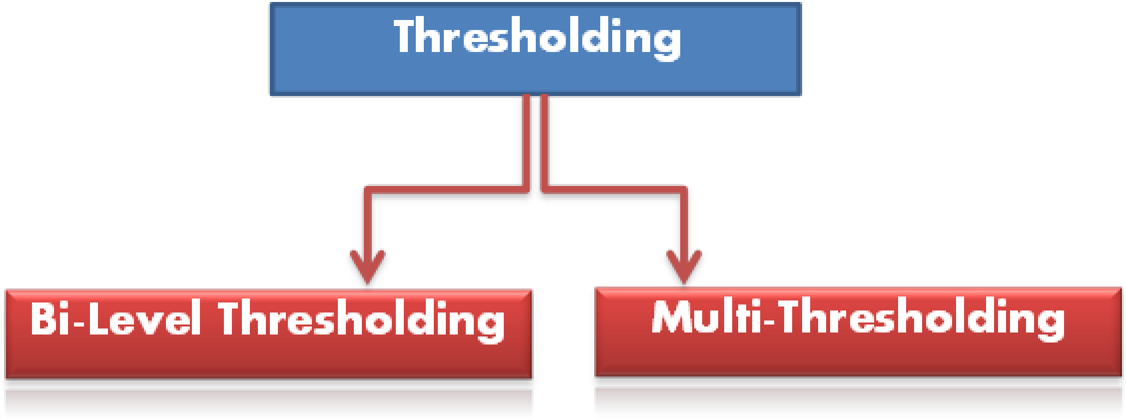
Feature Selection

Classification and Recognition

IMAGE SEGMENTATION (CONTINUED)

In computer vision, image segmentation is the process of partitioning a digital image into multiple homogenous segments[1-3].

THRESHOLDING



Thresholding

Bi-Level Thresholding

Multi-Thresholding

THRESHOLDING (CONTINUED)

When the image has segmented into two classes, the task is called Bi-level thresholding (BT) and requires only one (th) value, when pixels has separated into more than two classes, then the task is called as Multi-level Thresholding (MT) demands more than one (th) value.

THRESHOLDING (CONTINUED)

Original Image

BT

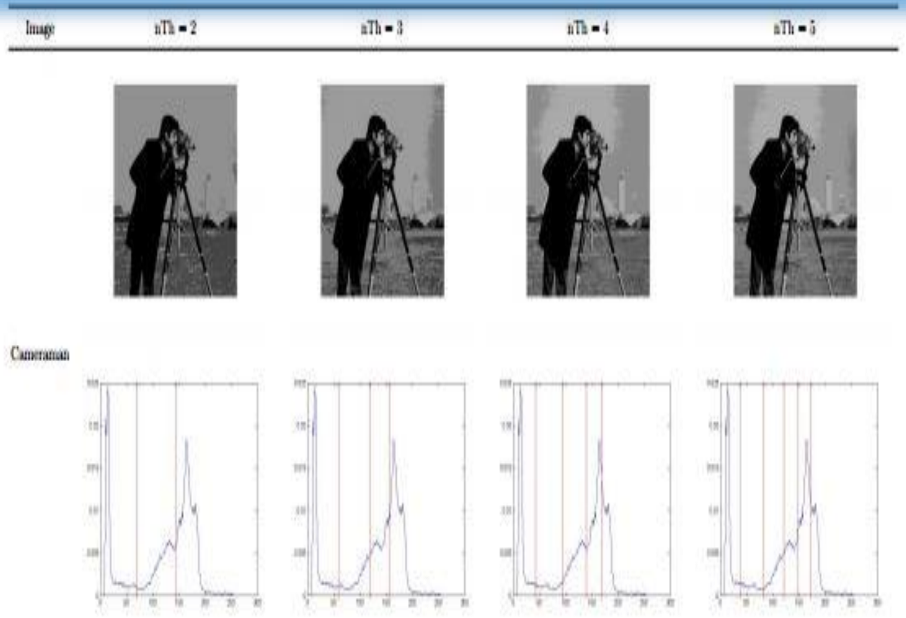
Segmented Image

THRESHOLDING (CONTINUED)

Input Image

MT

Segmented Images



THRESHOLDING (CONTINUED)

There are several methods used to find the optimal thresholding values such as Otsu 1979 [4] and Kapur’s1985 [5] methods.

OTSU’S OBJECTIVE FUNCTION

- Otsu proposed a thresholding technique based on the maximum variance between classes. This methods is used to find the optimal threshold values that separate the image into multiple classes .

$$F_{otsu}(TH) = Max(\sigma_B^2(th)) \text{ where } 0 \le th \le L-1 \text{ and } i = [1,2,3,\dots,k]$$

$$\sigma_B^2 = \sum_{i=1}^{k} \sigma_i = \sum_{i=1}^{k} \omega_1(\mu_1 - \mu_T)^2$$

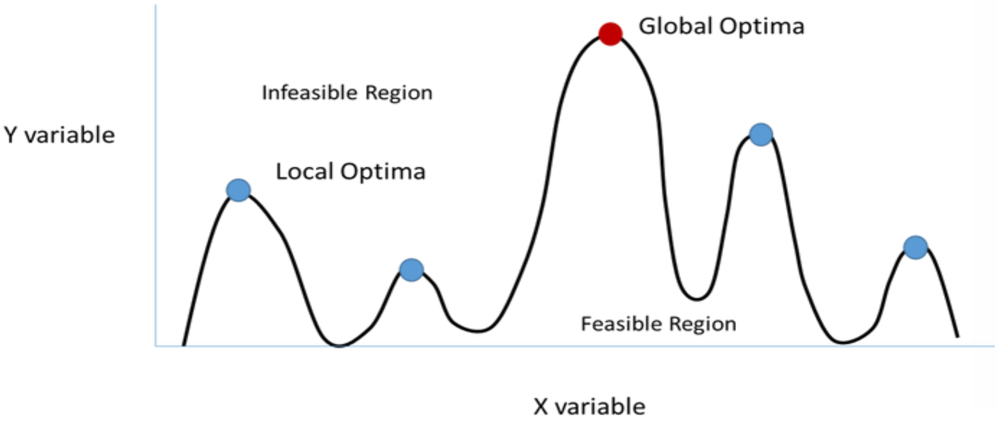
BI-LEVEL VS MULTI-LEVEL THRESHOLDING

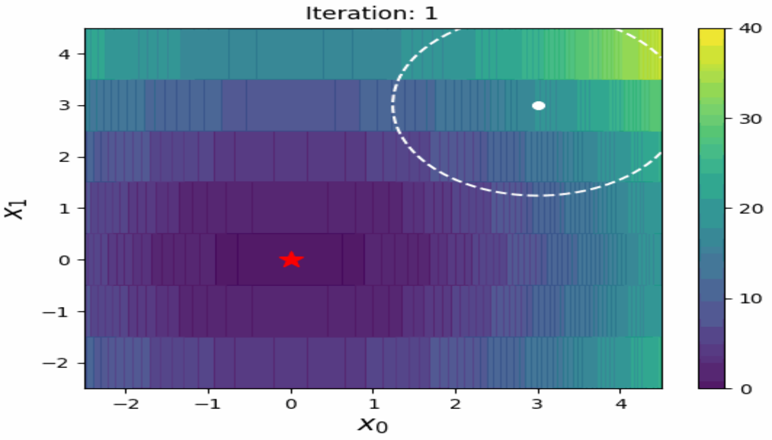
These methods are suitable for bi-level thresholding and they can be easily extended to multi-level case.

However the process of determining the optimal thresholds in case of multi-level is an exhaustive task [6].

BI-LEVEL VS MULTI-LEVEL THRESHOLDING (CONTINUED)

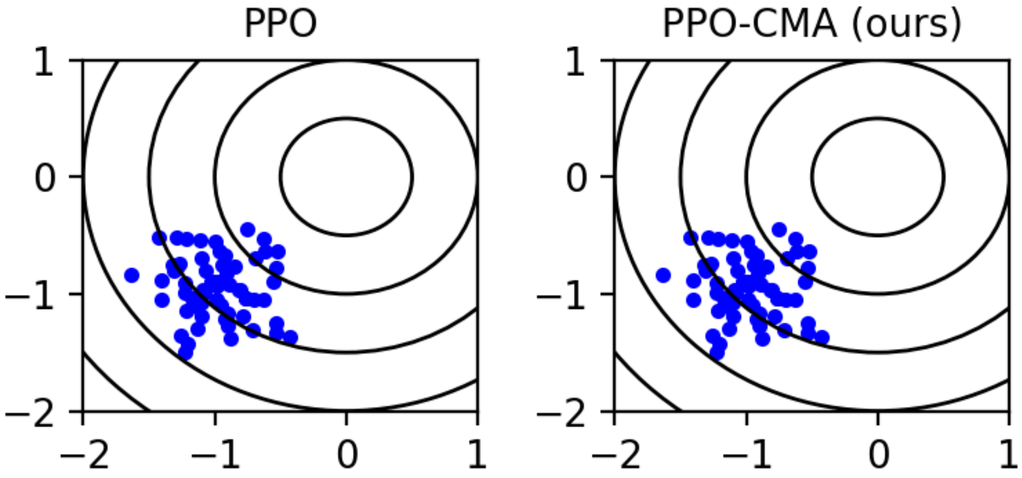
To avoid the thresholding problems, many researchers started to use Nature Inspired optimization algorithms (NIOA) to optimize the process of selecting the best thresholds [7].



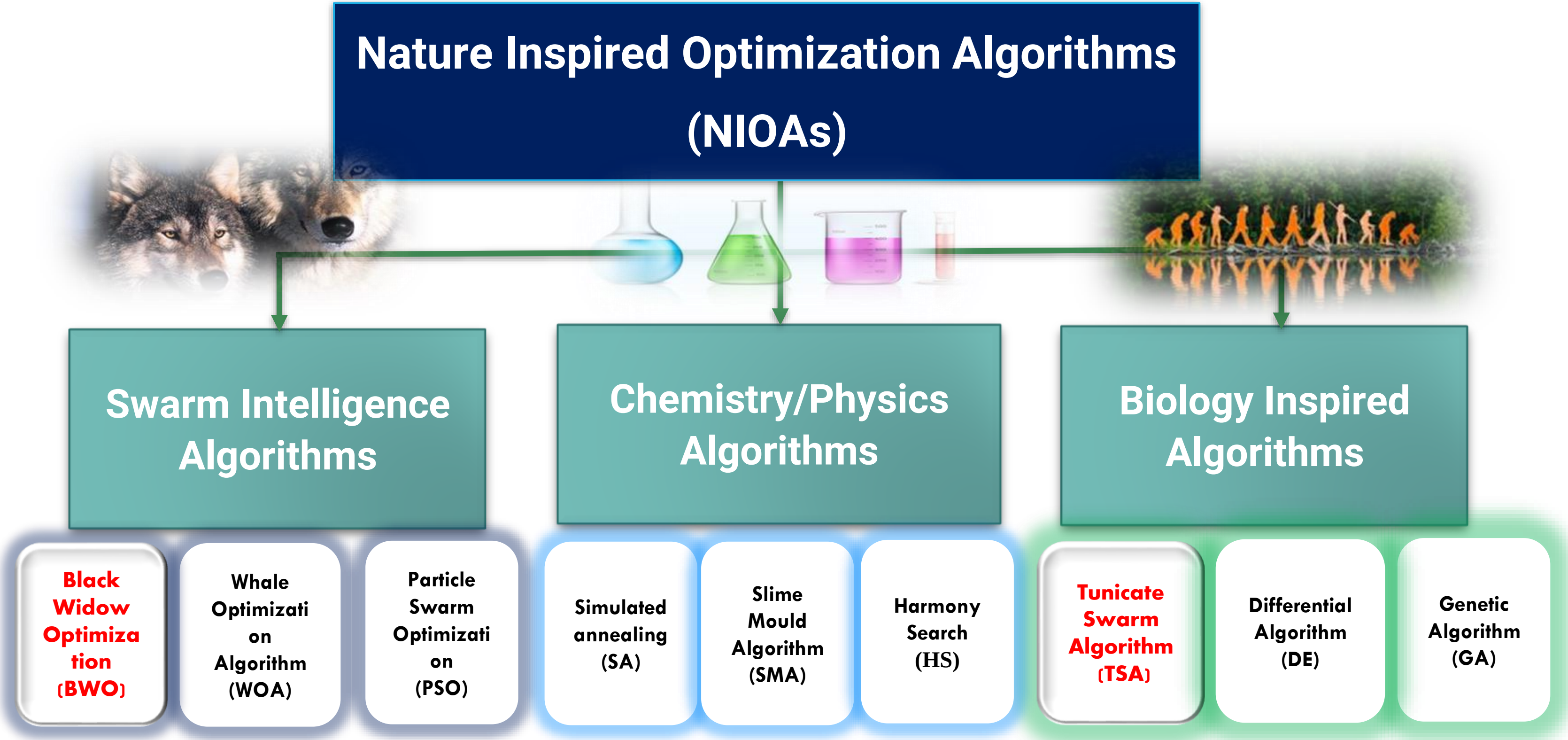


NATURE INSPIRED OPTIMIZATION ALGORITHMS

NIOAs have been designed and utilized for tackling many problems because of their simplicity and easy implementation process[8-9].



NIOAS (CONTINUED)



Nature Inspired Optimization Algorithms (NIOAs)

- **Swarm Intelligence Algorithms**
  - Black Widow Optimization (BWO)
  - Whale Optimization Algorithm (WOA)
  - Particle Swarm Optimization (PSO)
- **Chemistry/Physics Algorithms**
  - Simulated annealing (SA)
  - Slime Mould Algorithm (SMA)
  - Harmony Search (HS)
- **Biology Inspired Algorithms**
  - Tunicate Swarm Algorithm (TSA)
  - Differential Algorithm (DE)
  - Genetic Algorithm (GA)

NIOAS TACKLING MULTI-LEVEL THRESHOLDING PROBLEM

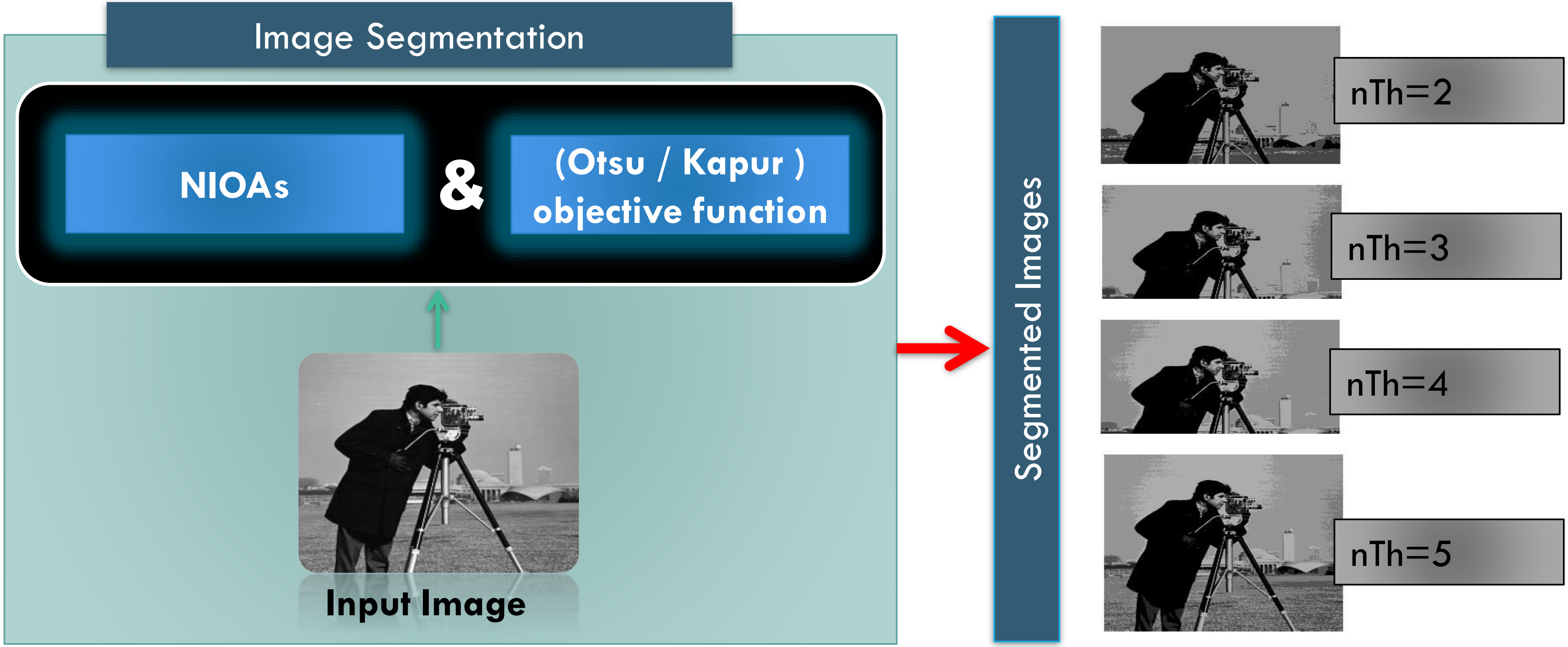


Image Segmentation

NIOAs

&

(Otsu / Kapur)
objective function

Input Image

Segmented Images

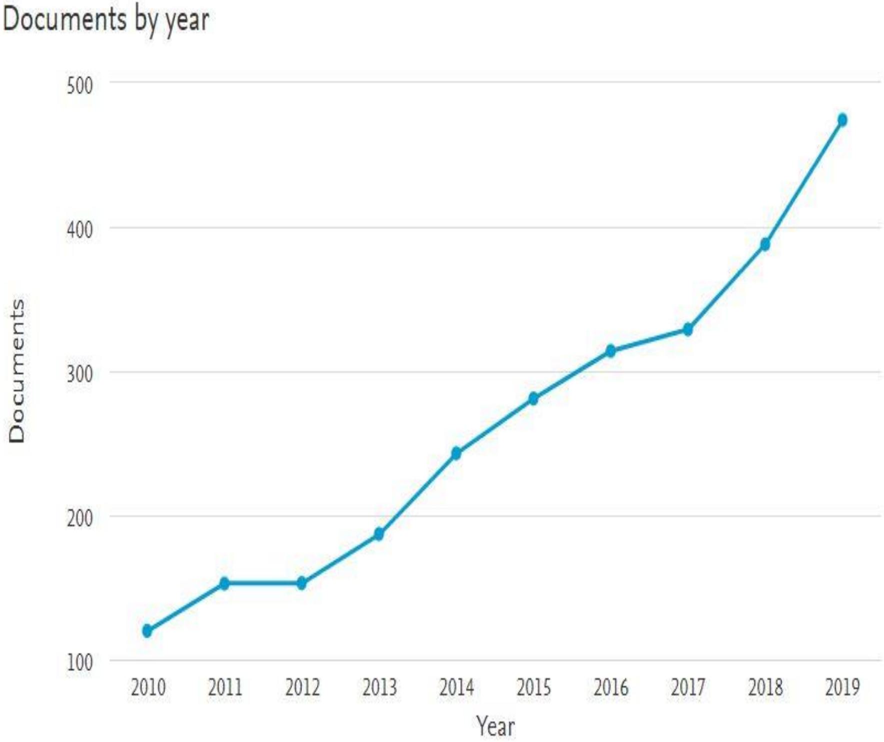
nTh=2

nTh=3

nTh=4

nTh=5

Number of publications of multi-level thresholding image segmentation over the last ten years, as announced by Scopus.



Distribution of multi-level thresholding image segmentation publications in several applications, as announced by Scopus.

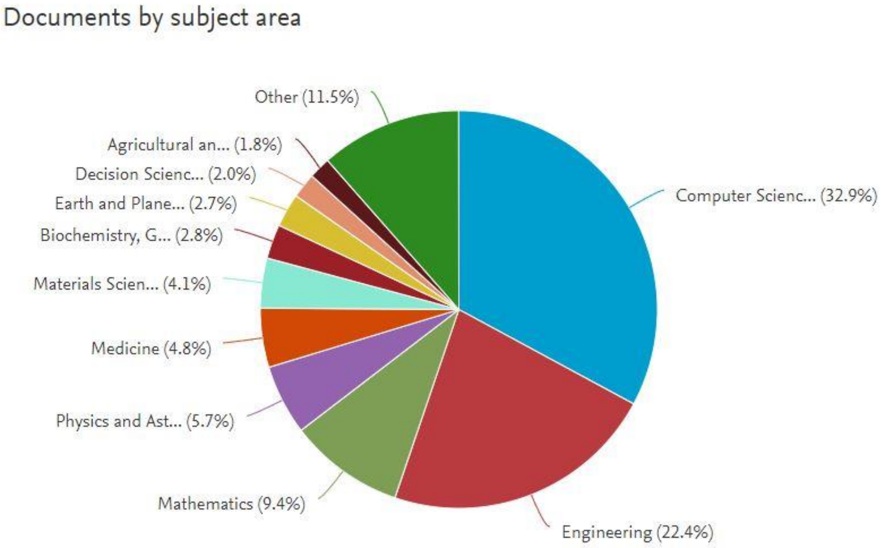
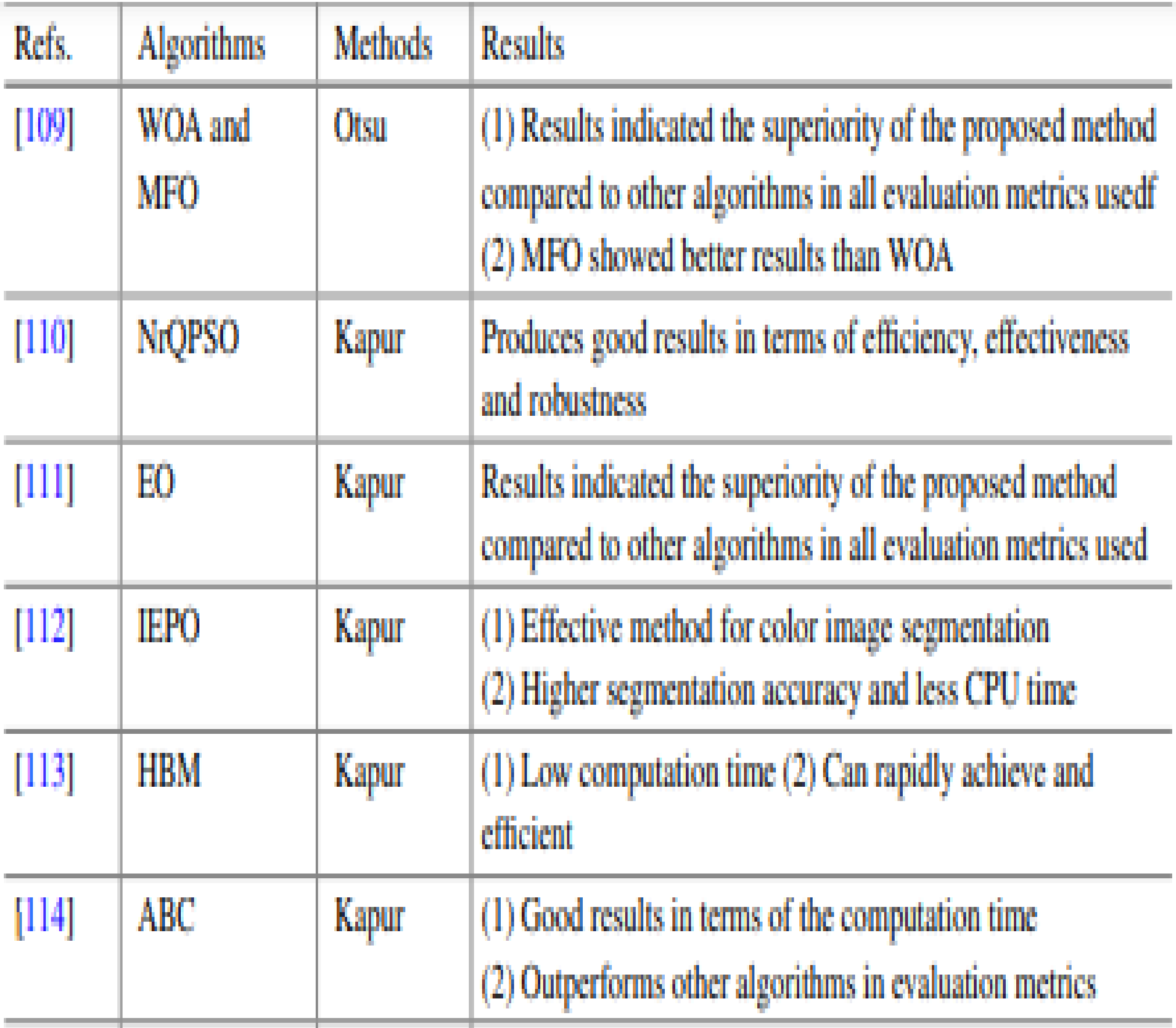
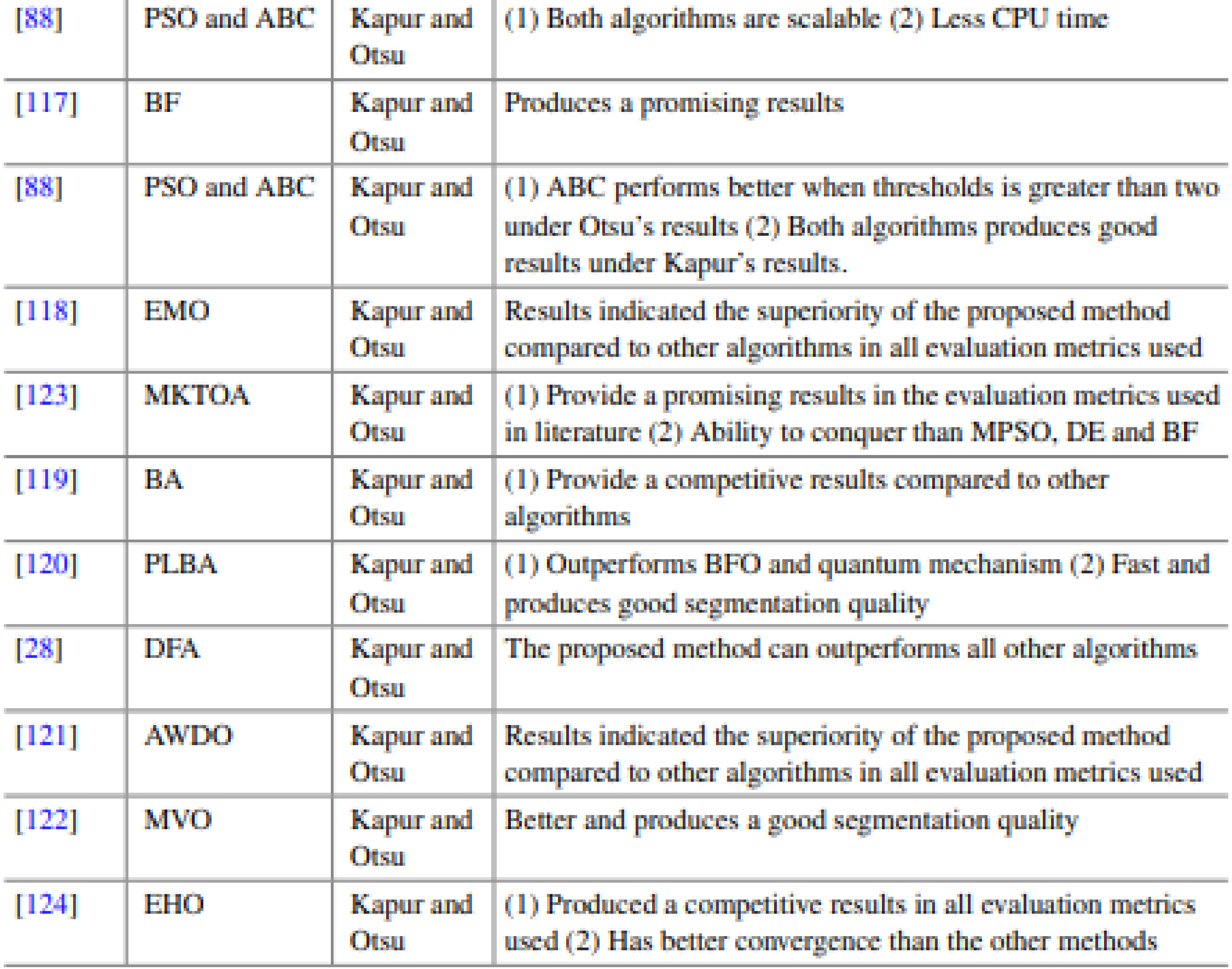


Table 1.1 Research works in image multi-level thresholding segmentation based nature-inspired optimization algorithms



Refs.	Algorithms	Methods	Results
[109]	WOA and MFO	Otsu	(1) Results indicated the superiority of the proposed method compared to other algorithms in all evaluation metrics usedf (2) MFO showed better results than WOA
[110]	NrQPSO	Kapur	Produces good results in terms of efficiency, effectiveness and robustness
[111]	EO	Kapur	Results indicated the superiority of the proposed method compared to other algorithms in all evaluation metrics used
[112]	IEPO	Kapur	(1) Effective method for color image segmentation (2) Higher segmentation accuracy and less CPU time
[113]	HBM	Kapur	(1) Low computation time (2) Can rapidly achieve and efficient
[114]	ABC	Kapur	(1) Good results in terms of the computation time (2) Outperforms other algorithms in evaluation metrics

Table 1.1 Research works in image multi-level thresholding segmentation based nature-inspired optimization algorithms



[88]	PSO and ABC	Kapur and Otsu	(1) Both algorithms are scalable (2) Less CPU time
[117]	BF	Kapur and Otsu	Produces a promising results
[88]	PSO and ABC	Kapur and Otsu	(1) ABC performs better when thresholds is greater than two under Otsu's results (2) Both algorithms produces good results under Kapur's results.
[118]	EMO	Kapur and Otsu	Results indicated the superiority of the proposed method compared to other algorithms in all evaluation metrics used
[123]	MKTOA	Kapur and Otsu	(1) Provide a promising results in the evaluation metrics used in literature (2) Ability to conquer than MPSO, DE and BF
[119]	BA	Kapur and Otsu	(1) Provide a competitive results compared to other algorithms
[120]	PLBA	Kapur and Otsu	(1) Outperforms BFO and quantum mechanism (2) Fast and produces good segmentation quality
[28]	DFA	Kapur and Otsu	The proposed method can outperforms all other algorithms
[121]	AWDO	Kapur and Otsu	Results indicated the superiority of the proposed method compared to other algorithms in all evaluation metrics used
[122]	MVO	Kapur and Otsu	Better and produces a good segmentation quality
[124]	EHO	Kapur and Otsu	(1) Produced a competitive results in all evaluation metrics used (2) Has better convergence than the other methods

Research paper :

An Improved Tunicate Swarm Algorithm for Global Optimization and Image Segmentation

Journal:

IEEE

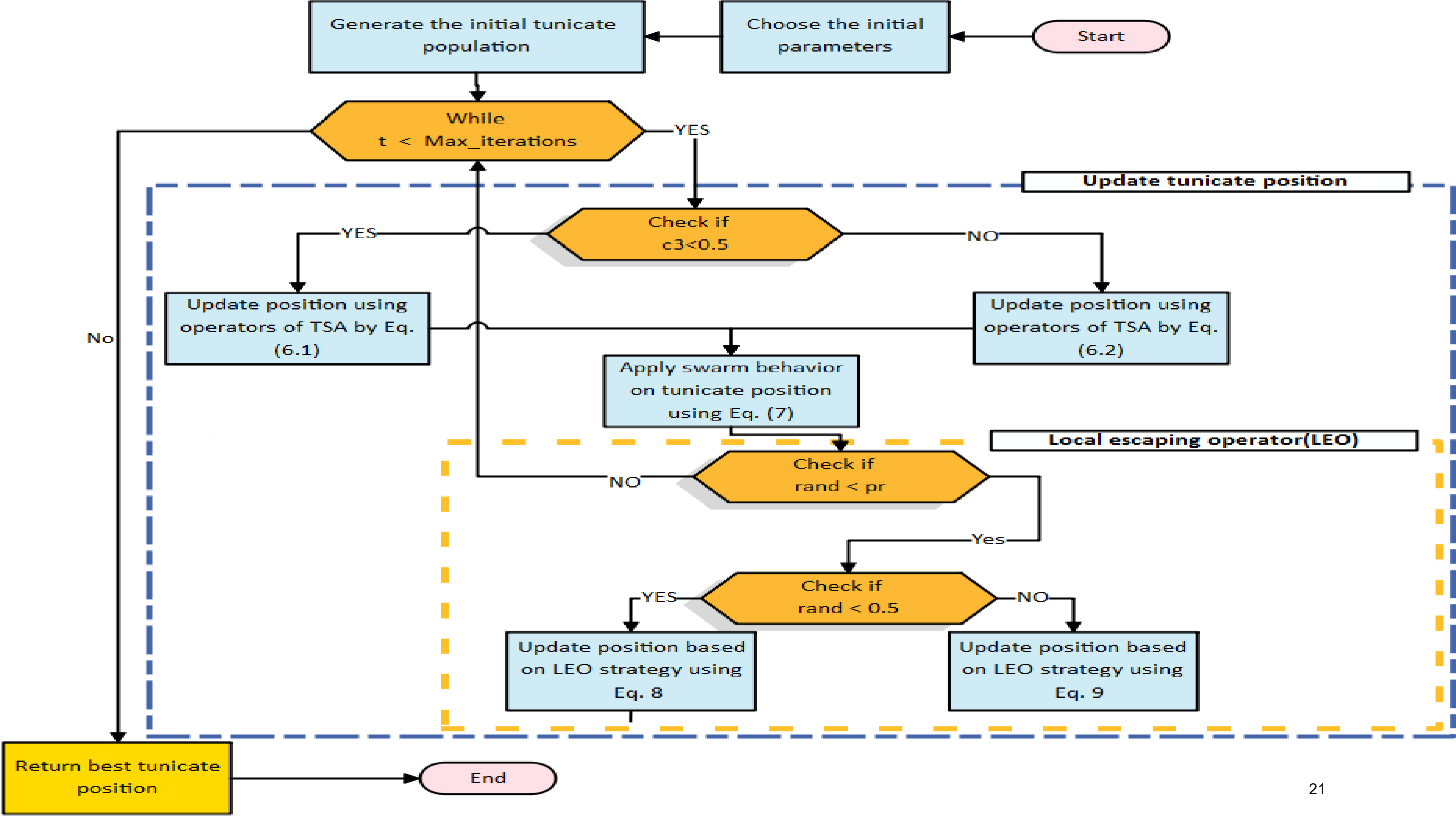
Impact Factor:

3.367

IEEE ACCESS

AN IMPROVED TUNICATE SWARM ALGORITHM FOR GLOBAL OPTIMIZATION AND IMAGE SEGMENTATION

This study [11] integrates a tunicate swarm algorithm (TSA) with a local escaping operator (LEO) for overcoming the weaknesses of the original TSA.


Start
Choose the initial parameters
Generate the initial tunicate population
While t < Max_iterations
YES
No
Update tunicate position
Check if c3<0.5
YES
NO
Update position using operators of TSA by Eq. (6.1)
Update position using operators of TSA by Eq. (6.2)
Apply swarm behavior on tunicate position using Eq. (7)
Local escaping operator(LEO)
Check if rand < pr
NO
Yes
Check if rand < 0.5
YES
NO
Update position based on LEO strategy using Eq. 8
Update position based on LEO strategy using Eq. 9
Return best tunicate position
End

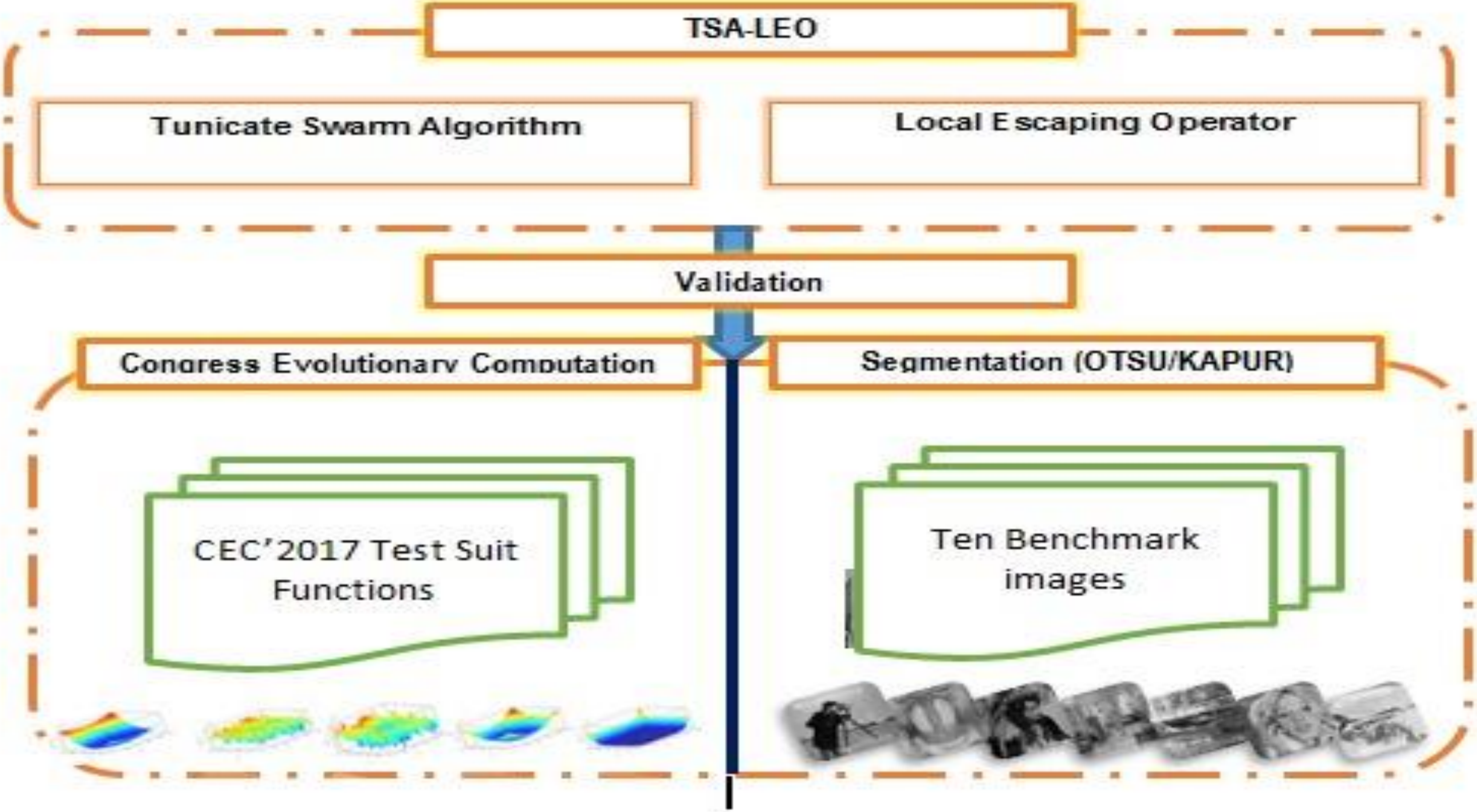
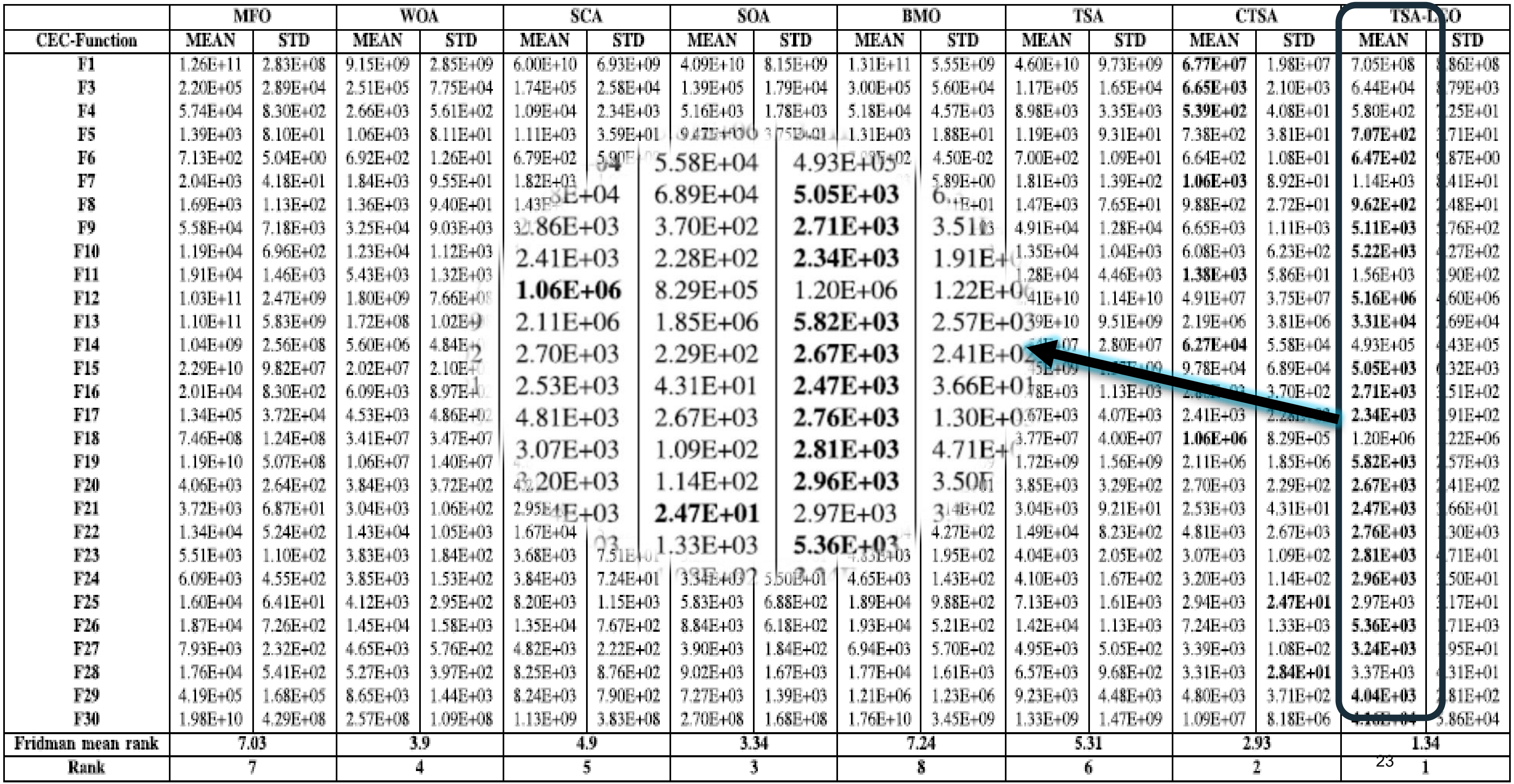

TSA-LEO
Tunicate Swarm Algorithm
Local Escaping Operator
Validation
Congress Evolutionary Computation
Segmentation (OTSU/KAPUR)
CEC'2017 Test Suit Functions
Ten Benchmark images

TABLE 2. Mean and STD of the fitness values of different optimization algorithms, obtained from 30 runs of 50-dimensional CEC'17 functions.

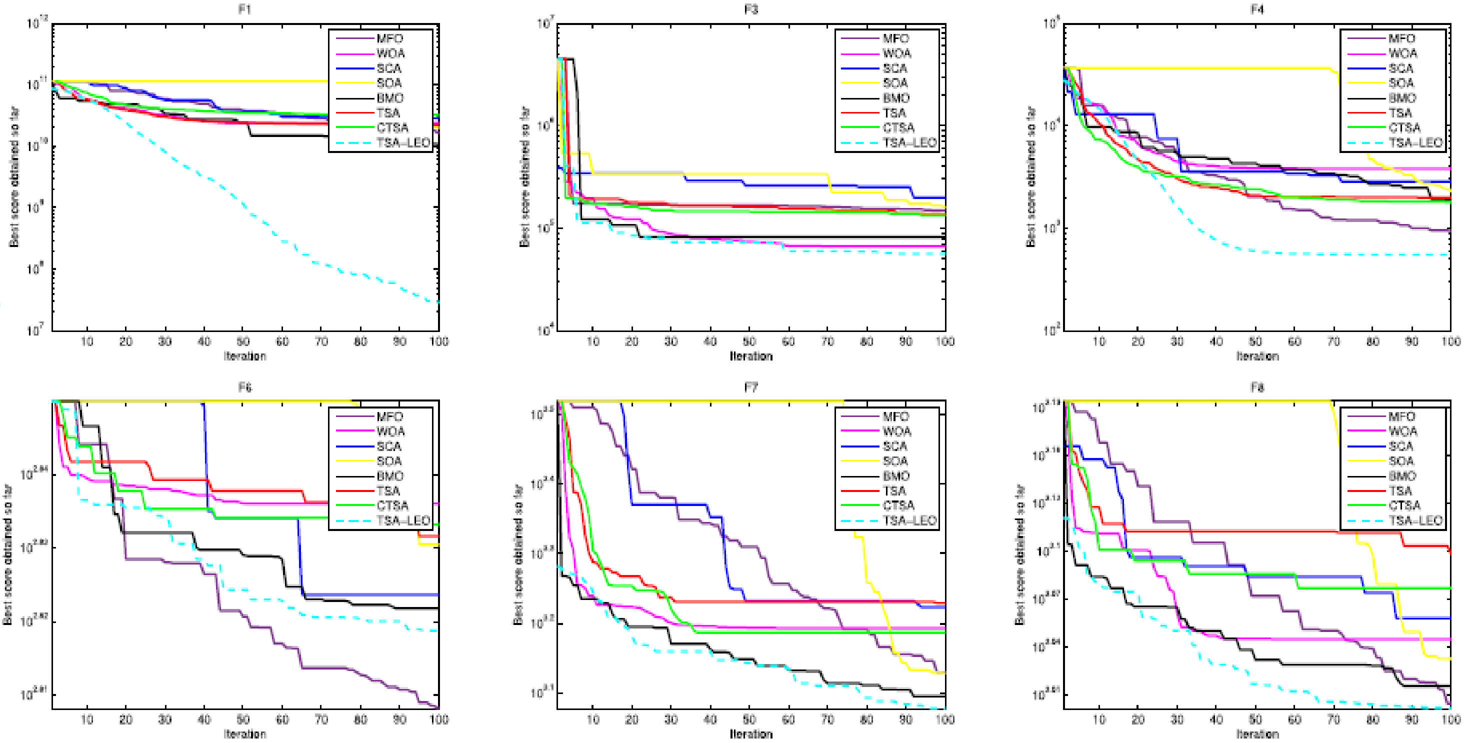


	MFO		WOA		SCA		SOA		BMO		TSA		CTSA		TSA-LEO	
CEC-Function	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
F1	1.26E+11	2.83E+08	9.15E+09	2.85E+09	6.00E+10	6.93E+09	4.09E+10	8.15E+09	1.31E+11	5.55E+09	4.60E+10	9.73E+09	**6.77E+07**	1.98E+07	7.05E+08	8.86E+08
F3	2.20E+05	2.89E+04	2.51E+05	7.75E+04	1.74E+05	2.58E+04	1.39E+05	1.79E+04	3.00E+05	5.60E+04	1.17E+05	1.65E+04	**6.65E+03**	2.10E+03	6.44E+04	8.79E+03
F4	5.74E+04	8.30E+02	2.66E+03	5.61E+02	1.09E+04	2.34E+03	5.16E+03	1.78E+03	5.18E+04	4.57E+03	8.98E+03	3.35E+03	**5.39E+02**	4.08E+01	5.80E+02	7.25E+01
F5	1.39E+03	8.10E+01	1.06E+03	8.11E+01	1.11E+03	3.59E+01	9.47E+00	3.75E+01	1.31E+03	1.88E+01	1.19E+03	9.31E+01	7.38E+02	3.81E+01	**7.07E+02**	3.71E+01
F6	7.13E+02	5.04E+00	6.92E+02	1.26E+01	6.79E+02	[illegible]	[illegible]	[illegible]	[illegible]	4.50E-02	7.00E+02	1.09E+01	6.64E+02	1.08E+01	**6.47E+02**	9.87E+00
F7	2.04E+03	4.18E+01	1.84E+03	9.55E+01	1.82E+03	[illegible]	[illegible]	[illegible]	[illegible]	5.89E+00	1.81E+03	1.39E+02	**1.06E+03**	8.92E+01	1.14E+03	8.41E+01
F8	1.69E+03	1.13E+02	1.36E+03	9.40E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.47E+03	7.65E+01	9.88E+02	2.72E+01	**9.62E+02**	2.48E+01
F9	5.58E+04	7.18E+03	3.25E+04	9.03E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.91E+04	1.28E+04	6.65E+03	1.11E+03	**5.11E+03**	5.76E+02
F10	1.19E+04	6.96E+02	1.23E+04	1.12E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.35E+04	1.04E+03	6.08E+03	6.23E+02	**5.22E+03**	4.27E+02
F11	1.91E+04	1.46E+03	5.43E+03	1.32E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.28E+04	4.46E+03	**1.38E+03**	5.86E+01	1.56E+03	3.90E+02
F12	1.03E+11	2.47E+09	1.80E+09	7.66E+08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.14E+10	4.91E+07	3.75E+07	**5.16E+06**	4.60E+06
F13	1.10E+11	5.83E+09	1.72E+08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.51E+09	2.19E+06	3.81E+06	**3.31E+04**	2.69E+04
F14	1.04E+09	2.56E+08	5.60E+06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.80E+07	**6.27E+04**	5.58E+04	4.93E+05	4.43E+05
F15	2.29E+10	9.82E+07	2.02E+07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.78E+04	6.89E+04	**5.05E+03**	6.32E+03
F16	2.01E+04	8.30E+02	6.09E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.13E+03	2.86E+03	3.70E+02	**2.71E+03**	3.51E+02
F17	1.34E+05	3.72E+04	4.53E+03	4.86E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.07E+03	2.41E+03	2.28E+02	**2.34E+03**	1.91E+02
F18	7.46E+08	1.24E+08	3.41E+07	3.47E+07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.77E+07	4.00E+07	**1.06E+06**	8.29E+05	1.20E+06	1.22E+06
F19	1.19E+10	5.07E+08	1.06E+07	1.40E+07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.72E+09	1.56E+09	2.11E+06	1.85E+06	**5.82E+03**	2.57E+03
F20	4.06E+03	2.64E+02	3.84E+03	3.72E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.85E+03	3.29E+02	2.70E+03	2.29E+02	**2.67E+03**	2.41E+02
F21	3.72E+03	6.87E+01	3.04E+03	1.06E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.04E+03	9.21E+01	2.53E+03	4.31E+01	**2.47E+03**	3.66E+01
F22	1.34E+04	5.24E+02	1.43E+04	1.05E+03	1.67E+04	[illegible]	[illegible]	[illegible]	[illegible]	4.27E+02	1.49E+04	8.23E+02	4.81E+03	2.67E+03	**2.76E+03**	1.30E+03
F23	5.51E+03	1.10E+02	3.83E+03	1.84E+02	3.68E+03	7.51E+01	[illegible]	[illegible]	[illegible]	1.95E+02	4.04E+03	2.05E+02	3.07E+03	1.09E+02	**2.81E+03**	4.71E+01
F24	6.09E+03	4.55E+02	3.85E+03	1.53E+02	3.84E+03	7.24E+01	3.34E+03	5.50E+01	4.65E+03	1.43E+02	4.10E+03	1.67E+02	3.20E+03	1.14E+02	**2.96E+03**	3.50E+01
F25	1.60E+04	6.41E+01	4.12E+03	2.95E+02	8.20E+03	1.15E+03	5.83E+03	6.88E+02	1.89E+04	9.88E+02	7.13E+03	1.61E+03	2.94E+03	**2.47E+01**	2.97E+03	3.17E+01
F26	1.87E+04	7.26E+02	1.45E+04	1.58E+03	1.35E+04	7.67E+02	8.84E+03	6.18E+02	1.93E+04	5.21E+02	1.42E+04	1.13E+03	7.24E+03	1.33E+03	**5.36E+03**	1.71E+03
F27	7.93E+03	2.32E+02	4.65E+03	5.76E+02	4.82E+03	2.22E+02	3.90E+03	1.84E+02	6.94E+03	5.70E+02	4.95E+03	5.05E+02	3.39E+03	1.08E+02	**3.24E+03**	1.95E+01
F28	1.76E+04	5.41E+02	5.27E+03	3.97E+02	8.25E+03	8.76E+02	9.02E+03	1.67E+03	1.77E+04	1.61E+03	6.57E+03	9.68E+02	3.31E+03	**2.84E+01**	3.37E+03	4.31E+01
F29	4.19E+05	1.68E+05	8.65E+03	1.44E+03	8.24E+03	7.90E+02	7.27E+03	1.39E+03	1.21E+06	1.23E+06	9.23E+03	4.48E+03	4.80E+03	3.71E+02	**4.04E+03**	2.81E+02
F30	1.98E+10	4.29E+08	2.57E+08	1.09E+08	1.13E+09	3.83E+08	2.70E+08	1.68E+08	1.76E+10	3.45E+09	1.33E+09	1.47E+09	1.09E+07	8.18E+06	[illegible]	5.86E+04
Fridman mean rank	7.03		3.9		4.9		3.34		7.24		5.31		2.93		1.34	
Rank	7		4		5		3		8		6		2		1	

[illegible]	5.58E+04	4.93E+05	[illegible]
[illegible]	6.89E+04	**5.05E+03**	[illegible]
2.86E+03	3.70E+02	**2.71E+03**	[illegible]
2.41E+03	2.28E+02	**2.34E+03**	[illegible]
1.06E+06	8.29E+05	1.20E+06	[illegible]
2.11E+06	1.85E+06	**5.82E+03**	2.57E+03
2.70E+03	2.29E+02	**2.67E+03**	2.41E+02
2.53E+03	4.31E+01	**2.47E+03**	3.66E+01
4.81E+03	2.67E+03	**2.76E+03**	[illegible]
3.07E+03	1.09E+02	**2.81E+03**	[illegible]
3.20E+03	1.14E+02	**2.96E+03**	[illegible]
[illegible]	**2.47E+01**	2.97E+03	[illegible]
[illegible]	1.33E+03	**5.36E+03**	[illegible]

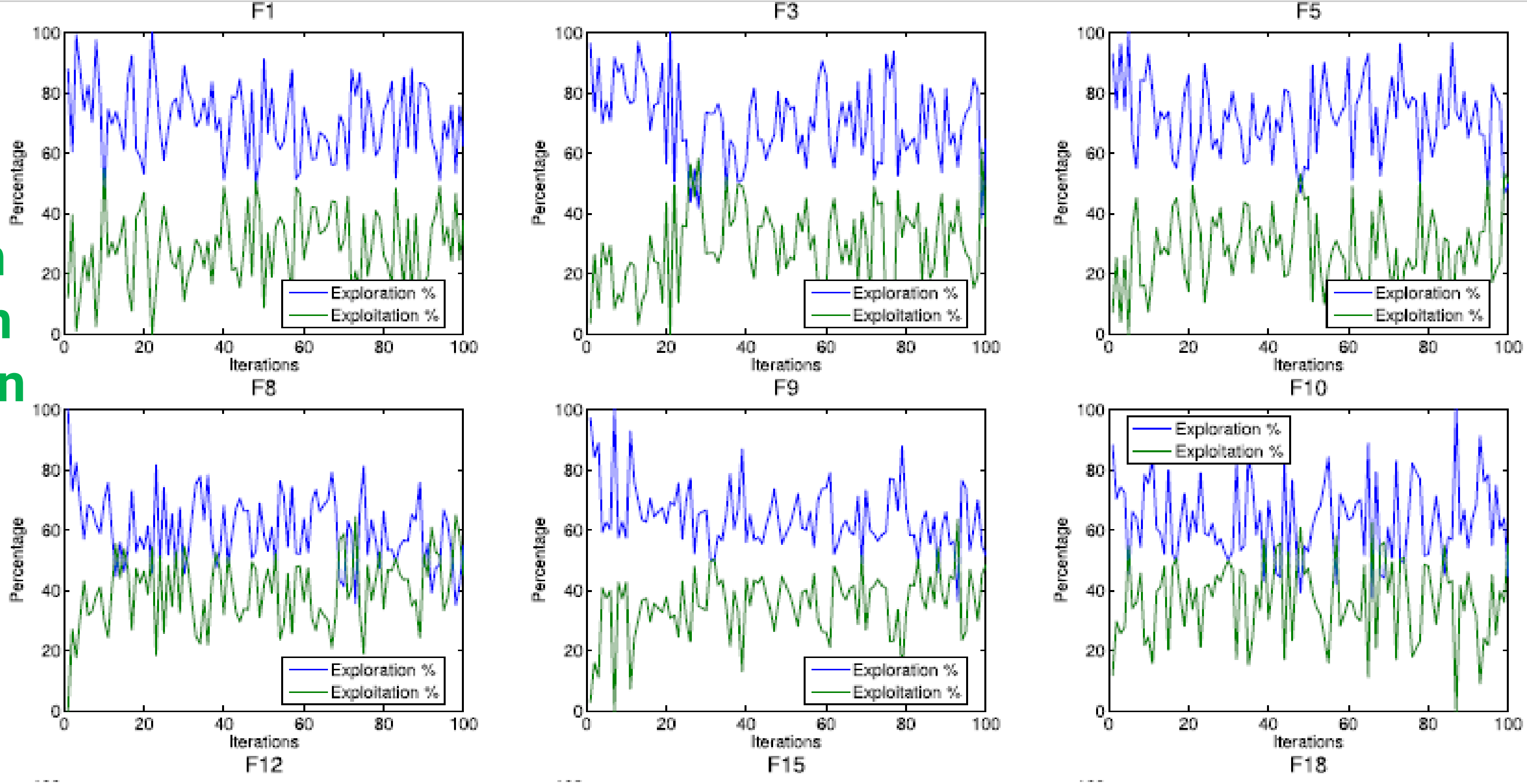
EXPERIMENTAL SERIES 1: CEC 2017

Convergence Curves



EXPERIMENTAL RESULTS

Exploration Exploitation Visualization



EXPERIMENTAL RESULTS (CONTINUED)

Boxplot

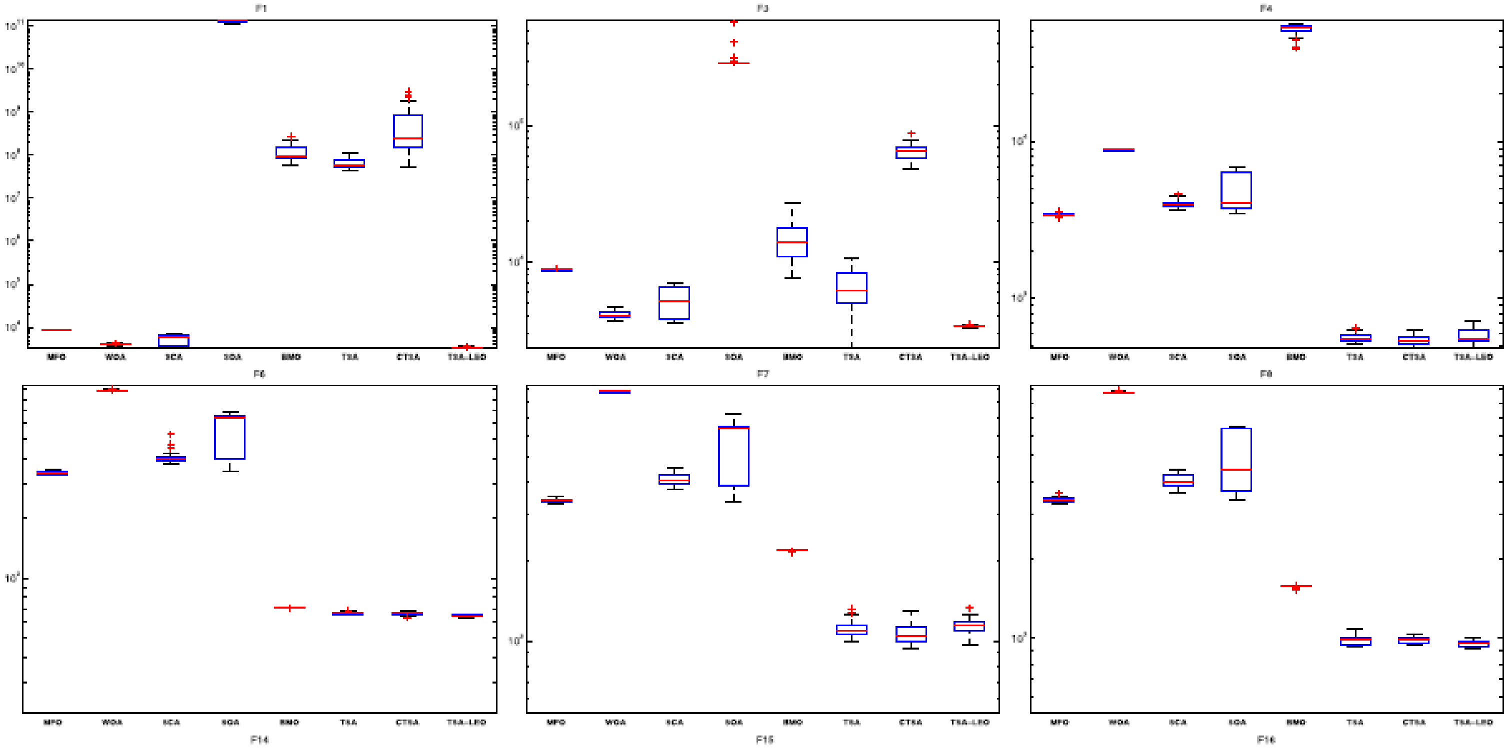
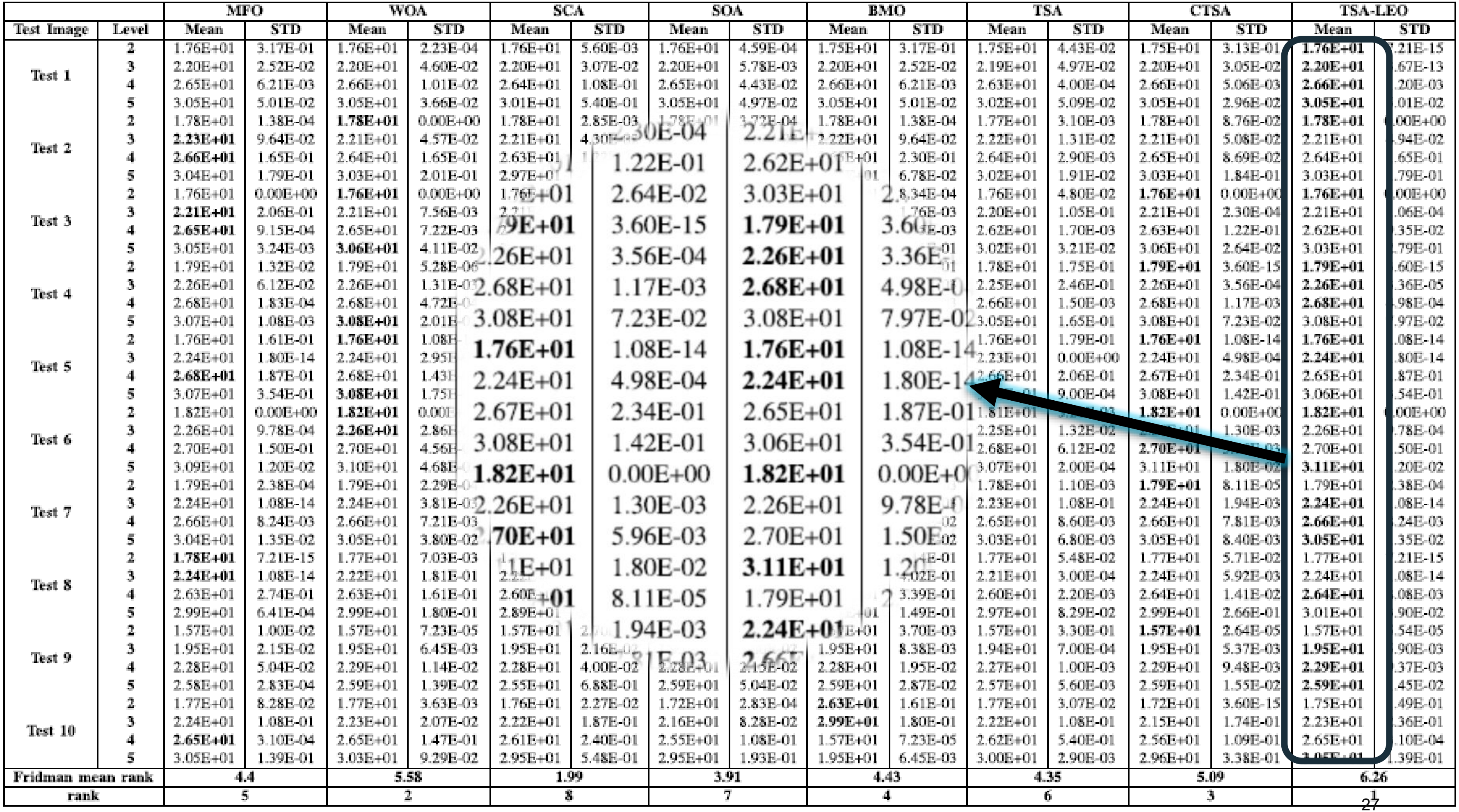
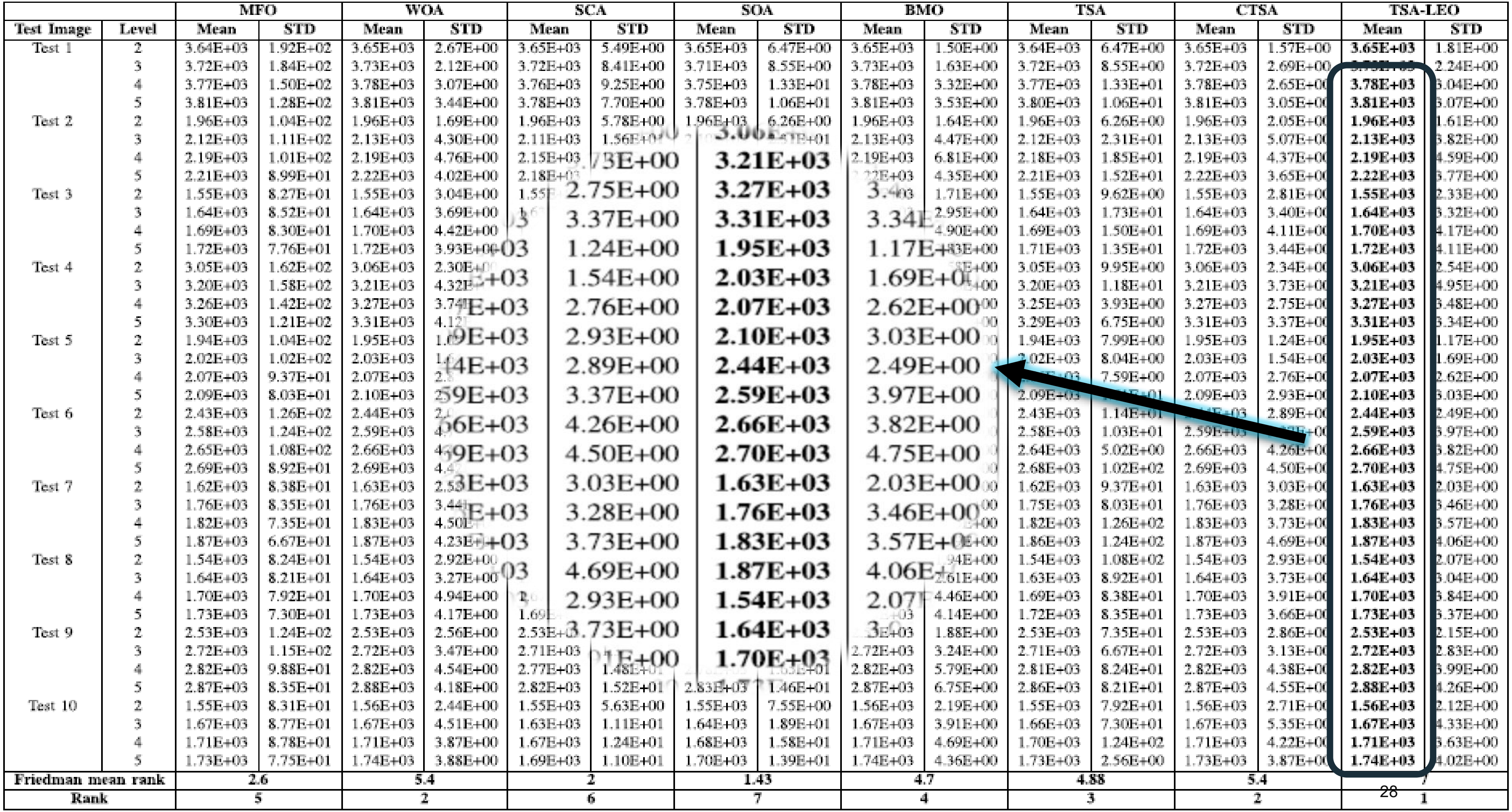


TABLE 7. Average and STD of Kapur's fitness obtained from all algorithms.



		MFO		WOA		SCA		SOA		BMO		TSA		CTSA		TSA-LEO	
Test Image	Level	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Test 1	2	1.76E+01	3.17E-01	1.76E+01	2.23E-04	1.76E+01	5.60E-03	1.76E+01	4.59E-04	1.75E+01	3.17E-01	1.75E+01	4.43E-02	1.75E+01	3.13E-01	**1.76E+01**	.21E-15
	3	2.20E+01	2.52E-02	2.20E+01	4.60E-02	2.20E+01	3.07E-02	2.20E+01	5.78E-03	2.20E+01	2.52E-02	2.19E+01	4.97E-02	2.20E+01	3.05E-02	**2.20E+01**	.67E-13
	4	2.65E+01	6.21E-03	2.66E+01	1.01E-02	2.64E+01	1.08E-01	2.65E+01	4.43E-02	2.66E+01	6.21E-03	2.63E+01	4.00E-04	2.66E+01	5.06E-03	**2.66E+01**	.20E-03
	5	3.05E+01	5.01E-02	3.05E+01	3.66E-02	3.01E+01	5.40E-01	3.05E+01	4.97E-02	3.05E+01	5.01E-02	3.02E+01	5.09E-02	3.05E+01	2.96E-02	**3.05E+01**	.01E-02
Test 2	2	1.78E+01	1.38E-04	**1.78E+01**	0.00E+00	1.78E+01	2.85E-03	1.78E+01	3.72E-04	1.78E+01	1.38E-04	1.77E+01	3.10E-03	1.78E+01	8.76E-02	**1.78E+01**	.00E+00
	3	**2.23E+01**	9.64E-02	2.21E+01	4.57E-02	2.21E+01	[illegible]	[illegible]	[illegible]	2.22E+01	9.64E-02	2.22E+01	1.31E-02	2.21E+01	5.08E-02	2.21E+01	.94E-02
	4	**2.66E+01**	1.65E-01	2.64E+01	1.65E-01	2.63E+01	[illegible]	[illegible]	[illegible]	[illegible]	2.30E-01	2.64E+01	2.90E-03	2.65E+01	8.69E-02	2.64E+01	.65E-01
	5	3.04E+01	1.79E-01	3.03E+01	2.01E-01	2.97E+01	[illegible]	[illegible]	[illegible]	[illegible]	6.78E-02	3.02E+01	1.91E-02	3.03E+01	1.84E-01	3.03E+01	.79E-01
Test 3	2	1.76E+01	0.00E+00	**1.76E+01**	0.00E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.34E-04	1.76E+01	4.80E-02	**1.76E+01**	0.00E+00	**1.76E+01**	.00E+00
	3	**2.21E+01**	2.06E-01	2.21E+01	7.56E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.20E+01	1.05E-01	2.21E+01	2.30E-04	2.21E+01	.06E-04
	4	**2.65E+01**	9.15E-04	2.65E+01	7.22E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.62E+01	1.70E-03	2.63E+01	1.22E-01	2.62E+01	.35E-02
	5	3.05E+01	3.24E-03	**3.06E+01**	4.11E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.02E+01	3.21E-02	3.06E+01	2.64E-02	3.03E+01	.79E-01
Test 4	2	1.79E+01	1.32E-02	1.79E+01	5.28E-06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.78E+01	1.75E-01	**1.79E+01**	3.60E-15	**1.79E+01**	.60E-15
	3	2.26E+01	6.12E-02	2.26E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.25E+01	2.46E-01	2.26E+01	3.56E-04	**2.26E+01**	.36E-05
	4	2.68E+01	1.83E-04	2.68E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.66E+01	1.50E-03	2.68E+01	1.17E-03	**2.68E+01**	.98E-04
	5	3.07E+01	1.08E-03	**3.08E+01**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.05E+01	1.65E-01	3.08E+01	7.23E-02	3.08E+01	.97E-02
Test 5	2	1.76E+01	1.61E-01	**1.76E+01**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.76E+01	1.79E-01	**1.76E+01**	1.08E-14	**1.76E+01**	.08E-14
	3	2.24E+01	1.80E-14	2.24E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.23E+01	0.00E+00	2.24E+01	4.98E-04	**2.24E+01**	.80E-14
	4	**2.68E+01**	1.87E-01	2.68E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.66E+01	2.06E-01	2.67E+01	2.34E-01	2.65E+01	.87E-01
	5	3.07E+01	3.54E-01	**3.08E+01**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.00E-04	3.08E+01	1.42E-01	3.06E+01	.54E-01
Test 6	2	1.82E+01	0.00E+00	**1.82E+01**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.81E+01	[illegible]	**1.82E+01**	0.00E+00	**1.82E+01**	.00E+00
	3	2.26E+01	9.78E-04	**2.26E+01**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.25E+01	1.32E-02	[illegible]	1.30E-03	2.26E+01	.78E-04
	4	2.70E+01	1.50E-01	2.70E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.68E+01	6.12E-02	**2.70E+01**	[illegible]	2.70E+01	.50E-01
	5	3.09E+01	1.20E-02	3.10E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.07E+01	2.00E-04	3.11E+01	1.80E-02	**3.11E+01**	.20E-02
Test 7	2	1.79E+01	2.38E-04	1.79E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.78E+01	1.10E-03	**1.79E+01**	8.11E-05	1.79E+01	.38E-04
	3	2.24E+01	1.08E-14	2.24E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.23E+01	1.08E-01	2.24E+01	1.94E-03	**2.24E+01**	.08E-14
	4	2.66E+01	8.24E-03	2.66E+01	7.21E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.65E+01	8.60E-03	2.66E+01	7.81E-03	**2.66E+01**	.24E-03
	5	3.04E+01	1.35E-02	3.05E+01	3.80E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.03E+01	6.80E-03	3.05E+01	8.40E-03	**3.05E+01**	.35E-02
Test 8	2	**1.78E+01**	7.21E-15	1.77E+01	7.03E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.77E+01	5.48E-02	1.77E+01	5.71E-02	1.77E+01	.21E-15
	3	**2.24E+01**	1.08E-14	2.22E+01	1.81E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.21E+01	3.00E-04	2.24E+01	5.92E-03	2.24E+01	.08E-14
	4	2.63E+01	2.74E-01	2.63E+01	1.61E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.39E-01	2.60E+01	2.20E-03	2.64E+01	1.41E-02	**2.64E+01**	.08E-03
	5	2.99E+01	6.41E-04	2.99E+01	1.80E-01	2.89E+01	[illegible]	[illegible]	[illegible]	[illegible]	1.49E-01	2.97E+01	8.29E-02	2.99E+01	2.66E-01	3.01E+01	.90E-02
Test 9	2	1.57E+01	1.00E-02	1.57E+01	7.23E-05	1.57E+01	[illegible]	[illegible]	[illegible]	[illegible]	3.70E-03	1.57E+01	3.30E-01	**1.57E+01**	2.64E-05	1.57E+01	.54E-05
	3	1.95E+01	2.15E-02	1.95E+01	6.45E-03	1.95E+01	[illegible]	[illegible]	[illegible]	1.95E+01	8.38E-03	1.94E+01	7.00E-04	1.95E+01	5.37E-03	**1.95E+01**	.90E-03
	4	2.28E+01	5.04E-02	2.29E+01	1.14E-02	2.28E+01	4.00E-02	2.28E+01	2.15E-02	2.28E+01	1.95E-02	2.27E+01	1.00E-03	2.29E+01	9.48E-03	**2.29E+01**	.37E-03
	5	2.58E+01	2.83E-04	2.59E+01	1.39E-02	2.55E+01	6.88E-01	2.59E+01	5.04E-02	2.59E+01	2.87E-02	2.57E+01	5.60E-03	2.59E+01	1.55E-02	**2.59E+01**	.45E-02
Test 10	2	1.77E+01	8.28E-02	1.77E+01	3.63E-03	1.76E+01	2.27E-02	1.72E+01	2.83E-04	**2.63E+01**	1.61E-01	1.77E+01	3.07E-02	1.72E+01	3.60E-15	1.75E+01	.49E-01
	3	2.24E+01	1.08E-01	2.23E+01	2.07E-02	2.22E+01	1.87E-01	2.16E+01	8.28E-02	**2.99E+01**	1.80E-01	2.22E+01	1.08E-01	2.15E+01	1.74E-01	2.23E+01	.36E-01
	4	**2.65E+01**	3.10E-04	2.65E+01	1.47E-01	2.61E+01	2.40E-01	2.55E+01	1.08E-01	1.57E+01	7.23E-05	2.62E+01	5.40E-01	2.56E+01	1.09E-01	2.65E+01	.10E-04
	5	3.05E+01	1.39E-01	3.03E+01	9.29E-02	2.95E+01	5.48E-01	2.95E+01	1.93E-01	1.95E+01	6.45E-03	3.00E+01	2.90E-03	2.96E+01	3.38E-01	[illegible]	1.39E-01
Fridman mean rank		4.4		5.58		1.99		3.91		4.43		4.35		5.09		6.26	
rank		5		2		8		7		4		6		3		1	

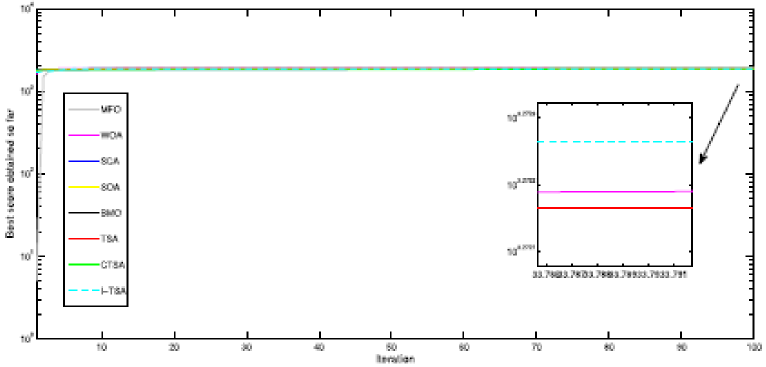
TABLE 15. Average and STD of Otsu's fitness obtained from all algorithms.

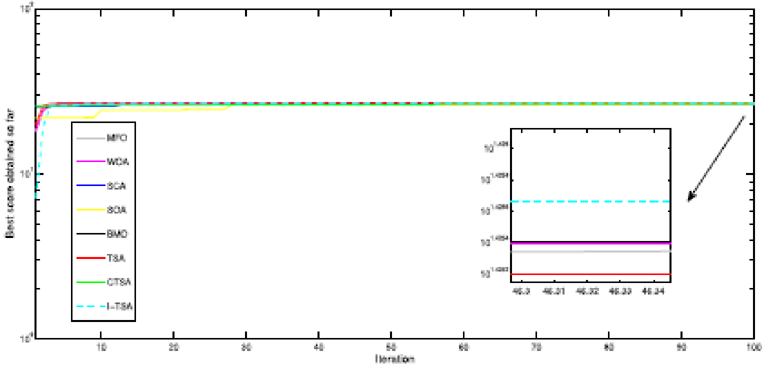


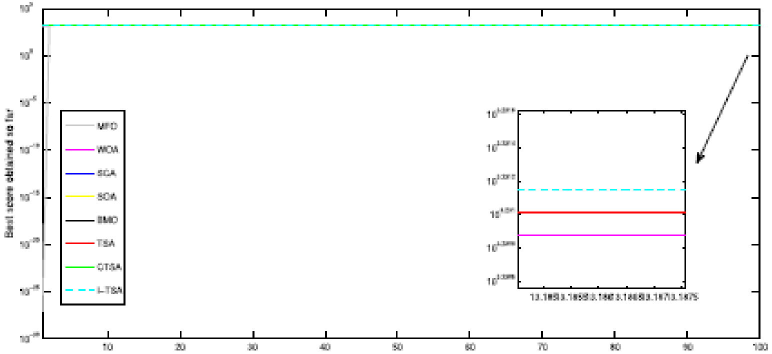
Test Image	Level	MFO		WOA		SCA		SOA		BMO		TSA		CTSA		TSA-LEO	
		Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Test 1	2	3.64E+03	1.92E+02	3.65E+03	2.67E+00	3.65E+03	5.49E+00	3.65E+03	6.47E+00	3.65E+03	1.50E+00	3.64E+03	6.47E+00	3.65E+03	1.57E+00	**3.65E+03**	1.81E+00
	3	3.72E+03	1.84E+02	3.73E+03	2.12E+00	3.72E+03	8.41E+00	3.71E+03	8.55E+00	3.73E+03	1.63E+00	3.72E+03	8.55E+00	3.72E+03	2.69E+00	[illegible]	2.24E+00
	4	3.77E+03	1.50E+02	3.78E+03	3.07E+00	3.76E+03	9.25E+00	3.75E+03	1.33E+01	3.78E+03	3.32E+00	3.77E+03	1.33E+01	3.78E+03	2.65E+00	**3.78E+03**	3.04E+00
	5	3.81E+03	1.28E+02	3.81E+03	3.44E+00	3.78E+03	7.70E+00	3.78E+03	1.06E+01	3.81E+03	3.53E+00	3.80E+03	1.06E+01	3.81E+03	3.05E+00	**3.81E+03**	3.07E+00
Test 2	2	1.96E+03	1.04E+02	1.96E+03	1.69E+00	1.96E+03	5.78E+00	1.96E+03	6.26E+00	1.96E+03	1.64E+00	1.96E+03	6.26E+00	1.96E+03	2.05E+00	**1.96E+03**	1.61E+00
	3	2.12E+03	1.11E+02	2.13E+03	4.30E+00	2.11E+03	1.56E+01	[illegible]	[illegible]	2.13E+03	4.47E+00	2.12E+03	2.31E+01	2.13E+03	5.07E+00	**2.13E+03**	3.82E+00
	4	2.19E+03	1.01E+02	2.19E+03	4.76E+00	2.15E+03	[illegible]	[illegible]	[illegible]	2.19E+03	6.81E+00	2.18E+03	1.85E+01	2.19E+03	4.37E+00	**2.19E+03**	4.59E+00
	5	2.21E+03	8.99E+01	2.22E+03	4.02E+00	2.18E+03	[illegible]	[illegible]	[illegible]	2.22E+03	4.35E+00	2.21E+03	1.52E+01	2.22E+03	3.65E+00	**2.22E+03**	3.77E+00
Test 3	2	1.55E+03	8.27E+01	1.55E+03	3.04E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.71E+00	1.55E+03	9.62E+00	1.55E+03	2.81E+00	**1.55E+03**	2.33E+00
	3	1.64E+03	8.52E+01	1.64E+03	3.69E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.95E+00	1.64E+03	1.73E+01	1.64E+03	3.40E+00	**1.64E+03**	3.32E+00
	4	1.69E+03	8.30E+01	1.70E+03	4.42E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.90E+00	1.69E+03	1.50E+01	1.69E+03	4.11E+00	**1.70E+03**	4.17E+00
	5	1.72E+03	7.76E+01	1.72E+03	3.93E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.71E+03	1.35E+01	1.72E+03	3.44E+00	**1.72E+03**	4.11E+00
Test 4	2	3.05E+03	1.62E+02	3.06E+03	2.30E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.05E+03	9.95E+00	3.06E+03	2.34E+00	**3.06E+03**	2.54E+00
	3	3.20E+03	1.58E+02	3.21E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.20E+03	1.18E+01	3.21E+03	3.73E+00	**3.21E+03**	4.95E+00
	4	3.26E+03	1.42E+02	3.27E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.25E+03	3.93E+00	3.27E+03	2.75E+00	**3.27E+03**	3.48E+00
	5	3.30E+03	1.21E+02	3.31E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.29E+03	6.75E+00	3.31E+03	3.37E+00	**3.31E+03**	3.34E+00
Test 5	2	1.94E+03	1.04E+02	1.95E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.94E+03	7.99E+00	1.95E+03	1.24E+00	**1.95E+03**	1.17E+00
	3	2.02E+03	1.02E+02	2.03E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.02E+03	8.04E+00	2.03E+03	1.54E+00	**2.03E+03**	1.69E+00
	4	2.07E+03	9.37E+01	2.07E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.59E+00	2.07E+03	2.76E+00	**2.07E+03**	2.62E+00
	5	2.09E+03	8.03E+01	2.10E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.09E+03	[illegible]	2.09E+03	2.93E+00	**2.10E+03**	3.03E+00
Test 6	2	2.43E+03	1.26E+02	2.44E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.43E+03	1.14E+01	[illegible]	2.89E+00	**2.44E+03**	2.49E+00
	3	2.58E+03	1.24E+02	2.59E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.58E+03	1.03E+01	2.59E+03	[illegible]	**2.59E+03**	3.97E+00
	4	2.65E+03	1.08E+02	2.66E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.64E+03	5.02E+00	2.66E+03	4.26E+00	**2.66E+03**	3.82E+00
	5	2.69E+03	8.92E+01	2.69E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.68E+03	1.02E+02	2.69E+03	4.50E+00	**2.70E+03**	4.75E+00
Test 7	2	1.62E+03	8.38E+01	1.63E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.62E+03	9.37E+01	1.63E+03	3.03E+00	**1.63E+03**	2.03E+00
	3	1.76E+03	8.35E+01	1.76E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.75E+03	8.03E+01	1.76E+03	3.28E+00	**1.76E+03**	3.46E+00
	4	1.82E+03	7.35E+01	1.83E+03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.82E+03	1.26E+02	1.83E+03	3.73E+00	**1.83E+03**	3.57E+00
	5	1.87E+03	6.67E+01	1.87E+03	4.23E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.86E+03	1.24E+02	1.87E+03	4.69E+00	**1.87E+03**	4.06E+00
Test 8	2	1.54E+03	8.24E+01	1.54E+03	2.92E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.54E+03	1.08E+02	1.54E+03	2.93E+00	**1.54E+03**	2.07E+00
	3	1.64E+03	8.21E+01	1.64E+03	3.27E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.61E+00	1.63E+03	8.92E+01	1.64E+03	3.73E+00	**1.64E+03**	3.04E+00
	4	1.70E+03	7.92E+01	1.70E+03	4.94E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.46E+00	1.69E+03	8.38E+01	1.70E+03	3.91E+00	**1.70E+03**	3.84E+00
	5	1.73E+03	7.30E+01	1.73E+03	4.17E+00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.14E+00	1.72E+03	8.35E+01	1.73E+03	3.66E+00	**1.73E+03**	3.37E+00
Test 9	2	2.53E+03	1.24E+02	2.53E+03	2.56E+00	2.53E+03	[illegible]	[illegible]	[illegible]	[illegible]	1.88E+00	2.53E+03	7.35E+01	2.53E+03	2.86E+00	**2.53E+03**	2.15E+00
	3	2.72E+03	1.15E+02	2.72E+03	3.47E+00	2.71E+03	[illegible]	[illegible]	[illegible]	2.72E+03	3.24E+00	2.71E+03	6.67E+01	2.72E+03	3.13E+00	**2.72E+03**	2.83E+00
	4	2.82E+03	9.88E+01	2.82E+03	4.54E+00	2.77E+03	1.48E+01	[illegible]	[illegible]	2.82E+03	5.79E+00	2.81E+03	8.24E+01	2.82E+03	4.38E+00	**2.82E+03**	3.99E+00
	5	2.87E+03	8.35E+01	2.88E+03	4.18E+00	2.82E+03	1.52E+01	2.83E+03	1.46E+01	2.87E+03	6.75E+00	2.86E+03	8.21E+01	2.87E+03	4.55E+00	**2.88E+03**	4.26E+00
Test 10	2	1.55E+03	8.31E+01	1.56E+03	2.44E+00	1.55E+03	5.63E+00	1.55E+03	7.55E+00	1.56E+03	2.19E+00	1.55E+03	7.92E+01	1.56E+03	2.71E+00	**1.56E+03**	2.12E+00
	3	1.67E+03	8.77E+01	1.67E+03	4.51E+00	1.63E+03	1.11E+01	1.64E+03	1.89E+01	1.67E+03	3.91E+00	1.66E+03	7.30E+01	1.67E+03	5.35E+00	**1.67E+03**	4.33E+00
	4	1.71E+03	8.78E+01	1.71E+03	3.87E+00	1.67E+03	1.24E+01	1.68E+03	1.58E+01	1.71E+03	4.69E+00	1.70E+03	1.24E+02	1.71E+03	4.22E+00	**1.71E+03**	3.63E+00
	5	1.73E+03	7.75E+01	1.74E+03	3.88E+00	1.69E+03	1.10E+01	1.70E+03	1.39E+01	1.74E+03	4.36E+00	1.73E+03	2.56E+00	1.73E+03	3.87E+00	**1.74E+03**	4.02E+00
Friedman mean rank		**2.6**		**5.4**		**2**		**1.43**		**4.7**		**4.88**		**5.4**		**7**	
Rank		**5**		**2**		**6**		**7**		**4**		**3**		**2**		**1**	

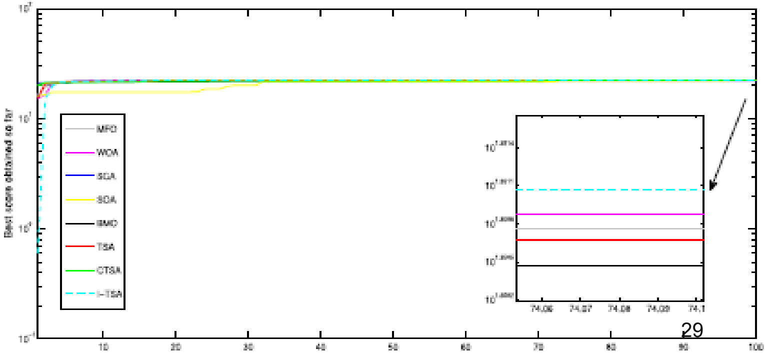
3.73E+00	**3.21E+03**	[illegible]
2.75E+00	**3.27E+03**	[illegible]
3.37E+00	**3.31E+03**	[illegible]
1.24E+00	**1.95E+03**	[illegible]
1.54E+00	**2.03E+03**	[illegible]
2.76E+00	**2.07E+03**	2.62E+00
2.93E+00	**2.10E+03**	3.03E+00
2.89E+00	**2.44E+03**	2.49E+00
3.37E+00	**2.59E+03**	3.97E+00
4.26E+00	**2.66E+03**	3.82E+00
4.50E+00	**2.70E+03**	4.75E+00
3.03E+00	**1.63E+03**	2.03E+00
3.28E+00	**1.76E+03**	3.46E+00
3.73E+00	**1.83E+03**	[illegible]
4.69E+00	**1.87E+03**	[illegible]
2.93E+00	**1.54E+03**	[illegible]
3.73E+00	**1.64E+03**	[illegible]
[illegible]	**1.70E+03**	[illegible]

EXPERIMENTAL RESULTS (CONTINUED)









Research paper :

A novel Black Widow Optimization algorithm for multilevel thresholding image segmentation

Journal:

Expert Systems with Applications

Impact Factor:

6.954

Expert Systems with Applications

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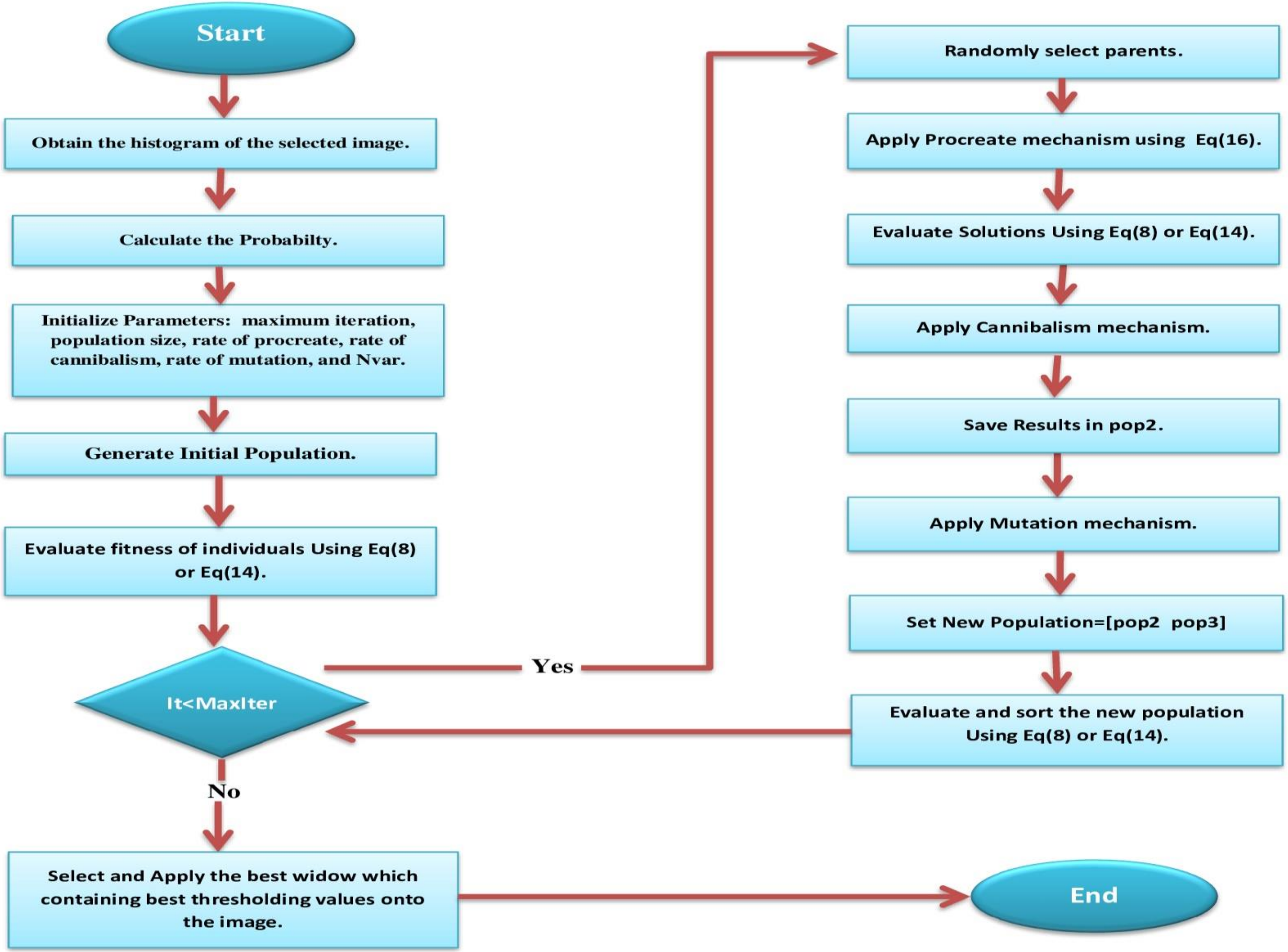
Binshan Lin

A NOVEL BLACK WIDOW OPTIMIZATION ALGORITHM FOR MULTILEVEL THRESHOLDING IMAGE SEGMENTATION

This paper [10] introduces the use of the novel meta-heuristic algorithm called Black Widow Optimization (BWO) to find the best threshold configuration using Otsu or Kapur as objective function.



Start

Obtain the histogram of the selected image.

Calculate the Probabilty.

Initialize Parameters: maximum iteration, population size, rate of procreate, rate of cannibalism, rate of mutation, and Nvar.

Generate Initial Population.

Evaluate fitness of individuals Using Eq(8) or Eq(14).

It<MaxIter

Yes

Randomly select parents.

Apply Procreate mechanism using Eq(16).

Evaluate Solutions Using Eq(8) or Eq(14).

Apply Cannibalism mechanism.

Save Results in pop2.

Apply Mutation mechanism.

Set New Population=[pop2 pop3]

Evaluate and sort the new population Using Eq(8) or Eq(14).

No

Select and Apply the best widow which containing best thresholding values onto the image.

End

Experimental Results

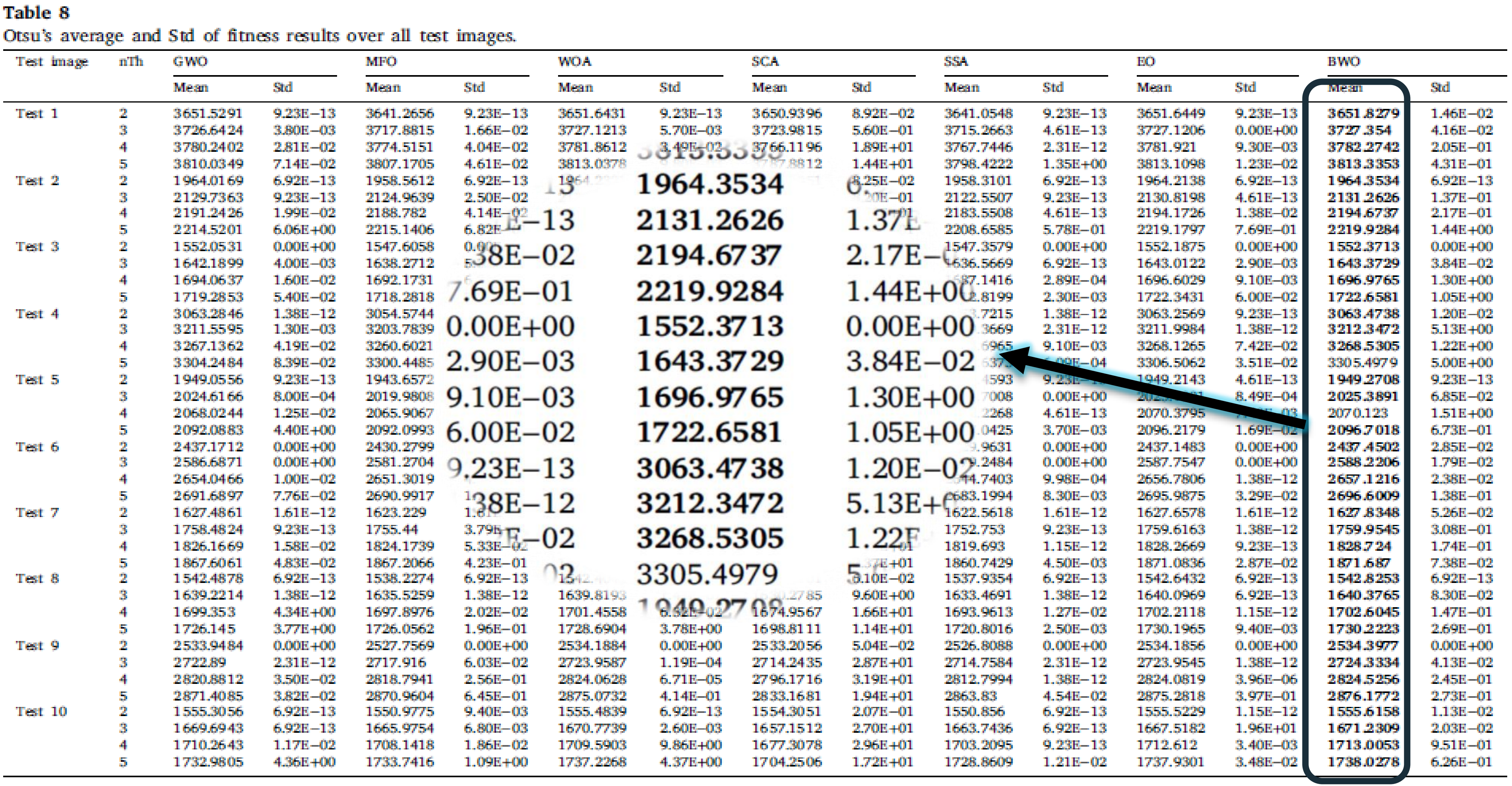


Table 8
Otsu's average and Std of fitness results over all test images.

Test image	nTh	GWO		MFO		WOA		SCA		SSA		EO		BWO	
		Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Test 1	2	3651.5291	9.23E−13	3641.2656	9.23E−13	3651.6431	9.23E−13	3650.9396	8.92E−02	3641.0548	9.23E−13	3651.6449	9.23E−13	3651.8279	1.46E−02
	3	3726.6424	3.80E−03	3717.8815	1.66E−02	3727.1213	5.70E−03	3723.9815	5.60E−01	3715.2663	4.61E−13	3727.1206	0.00E+00	3727.354	4.16E−02
	4	3780.2402	2.81E−02	3774.5151	4.04E−02	3781.8612	3.49E−02	3766.1196	1.89E+01	3767.7446	2.31E−12	3781.921	9.30E−03	3782.2742	2.05E−01
	5	3810.0349	7.14E−02	3807.1705	4.61E−02	3813.0378	[illegible]	[illegible]	1.44E+01	3798.4222	1.35E+00	3813.1098	1.23E−02	3813.3353	4.31E−01
Test 2	2	1964.0169	6.92E−13	1958.5612	6.92E−13	[illegible]	[illegible]	[illegible]	8.25E−02	1958.3101	6.92E−13	1964.2138	6.92E−13	1964.3534	6.92E−13
	3	2129.7363	9.23E−13	2124.9639	2.50E−02	[illegible]	[illegible]	[illegible]	[illegible]	2122.5507	9.23E−13	2130.8198	4.61E−13	2131.2626	1.37E−01
	4	2191.2426	1.99E−02	2188.782	4.14E−02	[illegible]	[illegible]	[illegible]	[illegible]	2183.5508	4.61E−13	2194.1726	1.38E−02	2194.6737	2.17E−01
	5	2214.5201	6.06E+00	2215.1406	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2208.6585	5.78E−01	2219.1797	7.69E−01	2219.9284	1.44E+00
Test 3	2	1552.0531	0.00E+00	1547.6058	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1547.3579	0.00E+00	1552.1875	0.00E+00	1552.3713	0.00E+00
	3	1642.1899	4.00E−03	1638.2712	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1636.5669	6.92E−13	1643.0122	2.90E−03	1643.3729	3.84E−02
	4	1694.0637	1.60E−02	1692.1731	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.89E−04	1696.6029	9.10E−03	1696.9765	1.30E+00
	5	1719.2853	5.40E−02	1718.2818	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.30E−03	1722.3431	6.00E−02	1722.6581	1.05E+00
Test 4	2	3063.2846	1.38E−12	3054.5744	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.38E−12	3063.2569	9.23E−13	3063.4738	1.20E−02
	3	3211.5595	1.30E−03	3203.7839	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.31E−12	3211.9984	1.38E−12	3212.3472	5.13E+00
	4	3267.1362	4.19E−02	3260.6021	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.10E−03	3268.1265	7.42E−02	3268.5305	1.22E+00
	5	3304.2484	8.39E−02	3300.4485	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3306.5062	3.51E−02	3305.4979	5.00E+00
Test 5	2	1949.0556	9.23E−13	1943.6572	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1949.2143	4.61E−13	1949.2708	9.23E−13
	3	2024.6166	8.00E−04	2019.9808	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	[illegible]	8.49E−04	2025.3891	6.85E−02
	4	2068.0244	1.25E−02	2065.9067	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.61E−13	2070.3795	[illegible]	2070.123	1.51E+00
	5	2092.0883	4.40E+00	2092.0993	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.70E−03	2096.2179	1.69E−02	2096.7018	6.73E−01
Test 6	2	2437.1712	0.00E+00	2430.2799	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	2437.1483	0.00E+00	2437.4502	2.85E−02
	3	2586.6871	0.00E+00	2581.2704	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00E+00	2587.7547	0.00E+00	2588.2206	1.79E−02
	4	2654.0466	1.00E−02	2651.3019	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.98E−04	2656.7806	1.38E−12	2657.1216	2.38E−02
	5	2691.6897	7.76E−02	2690.9917	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2683.1994	8.30E−03	2695.9875	3.29E−02	2696.6009	1.38E−01
Test 7	2	1627.4861	1.61E−12	1623.229	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1622.5618	1.61E−12	1627.6578	1.61E−12	1627.8348	5.26E−02
	3	1758.4824	9.23E−13	1755.44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1752.753	9.23E−13	1759.6163	1.38E−12	1759.9545	3.08E−01
	4	1826.1669	1.58E−02	1824.1739	5.33E−02	[illegible]	[illegible]	[illegible]	[illegible]	1819.693	1.15E−12	1828.2669	9.23E−13	1828.724	1.74E−01
	5	1867.6061	4.83E−02	1867.2066	4.23E−01	[illegible]	[illegible]	[illegible]	[illegible]	1860.7429	4.50E−03	1871.0836	2.87E−02	1871.687	7.38E−02
Test 8	2	1542.4878	6.92E−13	1538.2274	6.92E−13	[illegible]	[illegible]	[illegible]	[illegible]	1537.9354	6.92E−13	1542.6432	6.92E−13	1542.8253	6.92E−13
	3	1639.2214	1.38E−12	1635.5259	1.38E−12	1639.8193	[illegible]	[illegible]	9.60E+00	1633.4691	1.38E−12	1640.0969	6.92E−13	1640.3765	8.30E−02
	4	1699.353	4.34E+00	1697.8976	2.02E−02	1701.4558	[illegible]	1674.9567	1.66E+01	1693.9613	1.27E−02	1702.2118	1.15E−12	1702.6045	1.47E−01
	5	1726.145	3.77E+00	1726.0562	1.96E−01	1728.6904	3.78E+00	1698.8111	1.14E+01	1720.8016	2.50E−03	1730.1965	9.40E−03	1730.2223	2.69E−01
Test 9	2	2533.9484	0.00E+00	2527.7569	0.00E+00	2534.1884	0.00E+00	2533.2056	5.04E−02	2526.8088	0.00E+00	2534.1856	0.00E+00	2534.3977	0.00E+00
	3	2722.89	2.31E−12	2717.916	6.03E−02	2723.9587	1.19E−04	2714.2435	2.87E+01	2714.7584	2.31E−12	2723.9545	1.38E−12	2724.3334	4.13E−02
	4	2820.8812	3.50E−02	2818.7941	2.56E−01	2824.0628	6.71E−05	2796.1716	3.19E+01	2812.7994	1.38E−12	2824.0819	3.96E−06	2824.5256	2.45E−01
	5	2871.4085	3.82E−02	2870.9604	6.45E−01	2875.0732	4.14E−01	2833.1681	1.94E+01	2863.83	4.54E−02	2875.2818	3.97E−01	2876.1772	2.73E−01
Test 10	2	1555.3056	6.92E−13	1550.9775	9.40E−03	1555.4839	6.92E−13	1554.3051	2.07E−01	1550.856	6.92E−13	1555.5229	1.15E−12	1555.6158	1.13E−02
	3	1669.6943	6.92E−13	1665.9754	6.80E−03	1670.7739	2.60E−03	1657.1512	2.70E+01	1663.7436	6.92E−13	1667.5182	1.96E+01	1671.2309	2.03E−02
	4	1710.2643	1.17E−02	1708.1418	1.86E−02	1709.5903	9.86E+00	1677.3078	2.96E+01	1703.2095	9.23E−13	1712.612	3.40E−03	1713.0053	9.51E−01
	5	1732.9805	4.36E+00	1733.7416	1.09E+00	1737.2268	4.37E+00	1704.2506	1.72E+01	1728.8609	1.21E−02	1737.9301	3.48E−02	1738.0278	6.26E−01

1964.3534
2131.2626 1.37E
2194.6737 2.17E−
7.69E−01 2219.9284 1.44E+00
0.00E+00 1552.3713 0.00E+00
2.90E−03 1643.3729 3.84E−02
9.10E−03 1696.9765 1.30E+00
6.00E−02 1722.6581 1.05E+00
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E−02 3268.5305 1.22E
3305.4979

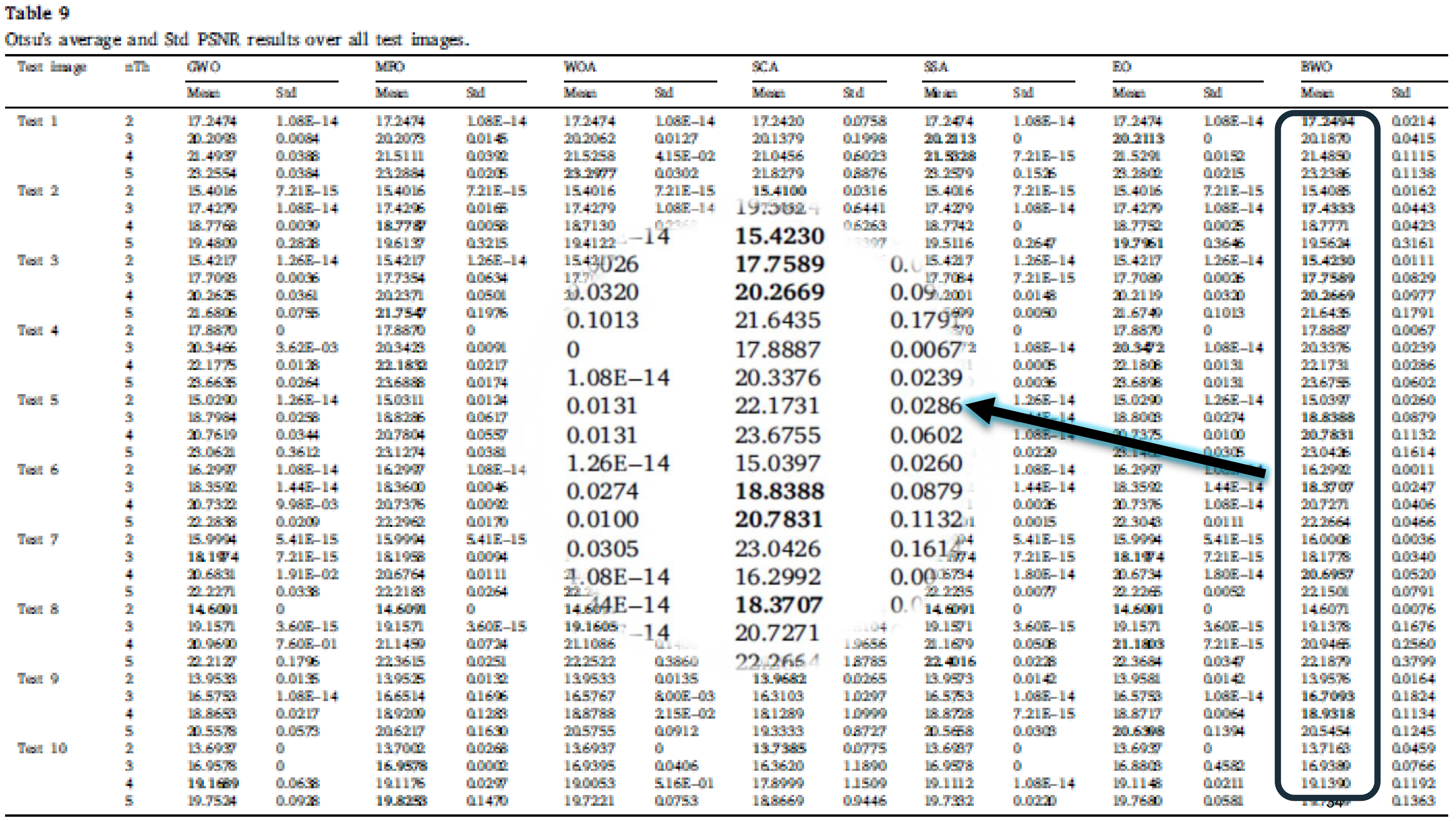

Table 9

Otsu's average and Std PSNR results over all test images.

Test image	nTh	GWO		MFO		WOA		SCA		SSA		EO		BWO	
		Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Test 1	2	17.2474	1.08E−14	17.2474	1.08E−14	17.2474	1.08E−14	17.2420	0.0758	17.2474	1.08E−14	17.2474	1.08E−14	17.2494	0.0214
	3	20.2098	0.0084	20.2073	0.0145	20.2062	0.0127	20.1379	0.1998	20.2113	0	20.2113	0	20.1870	0.0415
	4	21.4937	0.0388	21.5111	0.0392	21.5258	4.15E−02	21.0456	0.6023	21.5328	7.21E−15	21.5291	0.0152	21.4850	0.1115
	5	23.2554	0.0384	23.2884	0.0205	23.2977	0.0302	21.8279	0.8876	23.2579	0.1526	23.2802	0.0215	23.2386	0.1138
Test 2	2	15.4016	7.21E−15	15.4016	7.21E−15	15.4016	7.21E−15	15.4100	0.0316	15.4016	7.21E−15	15.4016	7.21E−15	15.4085	0.0162
	3	17.4279	1.08E−14	17.4296	0.0165	17.4279	1.08E−14	[illegible]	0.6441	17.4279	1.08E−14	17.4279	1.08E−14	17.4333	0.0443
	4	18.7768	0.0039	18.7787	0.0058	18.7130	[illegible]	[illegible]	0.6263	18.7742	0	18.7752	0.0025	18.7771	0.0423
	5	19.4809	0.2828	19.6137	0.3215	19.4122	[illegible]	[illegible]	[illegible]	19.5116	0.2647	19.7961	0.3646	19.5624	0.3161
Test 3	2	15.4217	1.26E−14	15.4217	1.26E−14	[illegible]	[illegible]	[illegible]	[illegible]	15.4217	1.26E−14	15.4217	1.26E−14	15.4230	0.0111
	3	17.7098	0.0036	17.7354	0.0634	[illegible]	[illegible]	[illegible]	[illegible]	17.7084	7.21E−15	17.7089	0.0026	17.7589	0.0829
	4	20.2625	0.0361	20.2371	0.0501	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0148	20.2119	0.0320	20.2669	0.0977
	5	21.6806	0.0755	21.7547	0.1976	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0050	21.6749	0.1013	21.6435	0.1791
Test 4	2	17.8870	0	17.8870	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	17.8870	0	17.8887	0.0067
	3	20.3466	3.62E−03	20.3423	0.0091	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.08E−14	20.3472	1.08E−14	20.3376	0.0239
	4	22.1775	0.0128	22.1832	0.0217	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0005	22.1808	0.0131	22.1731	0.0286
	5	23.6635	0.0264	23.6888	0.0174	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0036	23.6898	0.0131	23.6755	0.0602
Test 5	2	15.0290	1.26E−14	15.0311	0.0124	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.26E−14	15.0290	1.26E−14	15.0397	0.0260
	3	18.7984	0.0258	18.8286	0.0617	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.8003	0.0274	18.8388	0.0879
	4	20.7619	0.0344	20.7804	0.0557	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.08E−14	20.7375	0.0100	20.7831	0.1132
	5	23.0621	0.3612	23.1274	0.0381	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0229	[illegible]	0.0305	23.0426	0.1614
Test 6	2	16.2997	1.08E−14	16.2997	1.08E−14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.08E−14	16.2997	1.08E−14	16.2992	0.0011
	3	18.3592	1.44E−14	18.3600	0.0046	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.44E−14	18.3592	1.44E−14	18.3707	0.0247
	4	20.7322	9.98E−03	20.7376	0.0092	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0026	20.7376	1.08E−14	20.7271	0.0406
	5	22.2838	0.0209	22.2962	0.0170	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0015	22.3043	0.0111	22.2664	0.0466
Test 7	2	15.9994	5.41E−15	15.9994	5.41E−15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.41E−15	15.9994	5.41E−15	16.0008	0.0036
	3	18.1974	7.21E−15	18.1958	0.0094	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.21E−15	18.1974	7.21E−15	18.1778	0.0340
	4	20.6831	1.91E−02	20.6764	0.0111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.80E−14	20.6734	1.80E−14	20.6957	0.0520
	5	22.2271	0.0338	22.2183	0.0264	[illegible]	[illegible]	[illegible]	[illegible]	22.2235	0.0077	22.2265	0.0052	22.1501	0.0791
Test 8	2	14.6091	0	14.6091	0	[illegible]	[illegible]	[illegible]	[illegible]	14.6091	0	14.6091	0	14.6071	0.0076
	3	19.1571	3.60E−15	19.1571	3.60E−15	19.1605	[illegible]	[illegible]	[illegible]	19.1571	3.60E−15	19.1571	3.60E−15	19.1378	0.1676
	4	20.9690	7.60E−01	21.1459	0.0724	21.1086	[illegible]	[illegible]	1.9656	21.1679	0.0508	21.1803	7.21E−15	20.9465	0.2560
	5	22.2127	0.1796	22.3615	0.0251	22.2522	0.3860	[illegible]	1.8785	22.4016	0.0228	22.3684	0.0347	22.1879	0.3799
Test 9	2	13.9533	0.0135	13.9525	0.0132	13.9533	0.0135	13.9682	0.0265	13.9573	0.0142	13.9581	0.0142	13.9576	0.0164
	3	16.5753	1.08E−14	16.6514	0.1696	16.5767	8.00E−03	16.3103	1.0297	16.5753	1.08E−14	16.5753	1.08E−14	16.7093	0.1824
	4	18.8653	0.0217	18.9209	0.1283	18.8788	2.15E−02	18.1289	1.0999	18.8728	7.21E−15	18.8717	0.0064	18.9318	0.1134
	5	20.5578	0.0573	20.6217	0.1630	20.5755	0.0912	19.3333	0.8727	20.5658	0.0303	20.6398	0.1394	20.5454	0.1245
Test 10	2	13.6937	0	13.7002	0.0268	13.6937	0	13.7385	0.0775	13.6937	0	13.6937	0	13.7163	0.0459
	3	16.9578	0	16.9578	0.0002	16.9395	0.0406	16.3620	1.1890	16.9578	0	16.8803	0.4582	16.9389	0.0766
	4	19.1689	0.0638	19.1176	0.0297	19.0053	5.16E−01	17.8999	1.1509	19.1112	1.08E−14	19.1148	0.0211	19.1390	0.1192
	5	19.7524	0.0928	19.8258	0.1470	19.7221	0.0753	18.8669	0.9446	19.7332	0.0220	19.7680	0.0581	[illegible]	0.1363

A NOVEL BLACK WIDOW OPTIMIZATION ALGORITHM FOR MULTILEVEL THRESHOLDING IMAGE SEGMENTATION

The experimental results have revealed that the proposed BWO-based method outperform the competitor algorithms in terms of the fitness values as well as the others performance measures such as PSNR, SSIM and FSIM.

OPEN CHALLENGES

1. Selection of NIOA for MLT.

   It can be noticed that a massive set of NIOA has been introduced and exist in literature. Though, theoretically and practically, each NIOA's performance extensively depends on the problem under consideration i.e. the image type for MLT.

2. Selection of Objective Function.

   Proper selection of objective function for a NIOA based MLT model for a specific set of images is also very demanding. Numerous objective functions are developed in the literature which makes the selection more crucial.

3. Selection of Quality Parameters

   As such there is no single criterion for completing accurate segmentation for different variants of images. Furthermore, there is no one metric for evaluating the segmentation quality of an image segmentation technique across various image types.

CONCLUSION

- The problem of determining the optimal thresholding in case of multi-level thresholding for image segmentation is considered as optimization problem, so we tried to take the advantage of NIOAs to tackle such problem accuratelly.
- Multi-Level thresholding image segmentation problem formulated as an optimization problem.
- Black Widow Optimization Algorithm (BWO) employed to improve the quality of segmentation based thresholding techniques.
- A hybrid algorithm of Tunicate Swarm Algorithm (TSA) with Local Escaping Operator (TSA-LEO) introduced to cope with the original TSA’s inherent weaknesses.

CONCLUSION (CONTINUED)

The TSA-LEO’s performance is evaluated on:

- The CEC’17 test suite with 29 test functions.
- Image segmentation based on Multi-level thesholdig problem.

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THANKS FOR ATTENTION