

Performance Evaluation of Modified Adaptive Tabu Search Algorithms and Its Application

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Abstract

This paper presents a modified Adaptive Tabu Search Algorithm, namely mATS by adding an adaptive neighborhood mechanism under the main purpose enhancing search potential of ATS. An application of mATS to the real world problem is to solving the parameter identification problem of frequency modulation sounds (FMS) which is multimodal and also hard to solve by classical methods. Performance evaluations are elaborated with three surface optimization functions, Bohachevsky's, Rastrigin's and Shekel's foxholes. From the performance test, the results showed that the mATS were faster than those of the original ATS. Moreover, the proposed mATS approach obtained the better quality of the optimal solution than any other methods of previous works.

Keywords: Adaptive tabu search algorithms, Modified adaptive tabu search algorithms, frequency modulation sounds (selected from 1st Symposium on Hands-on Research and Development, Chiang Mai)

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1. Introduction

In this paper, modified Adaptive Tabu Search (mATS) is proposed for improving the search speed of the original ATS by adding an adaptive neighborhood mechanism, namely, AN with the purpose to manage number of neighborhood members such that the search converges to the global solution rapidly. An application of mATS to a real world problem concerned optimizing parameters identification of a multimodal system, namely frequency modulation sounds (FMS), is also elaborated. This paper is organized as follows. In Section 2, review of adaptive tabu search is presented. In Section 3, the modified adaptive tabu search algorithm is described. In Section 4, computational results are demonstrated. Finally, Section 5 is conclusion of this paper.

2. Adaptive Tabu Search Algorithms

Nearly a decade, adaptive tabu search (ATS) [2] was launched and has been widely applied in various fields, eg. control system design [3, 8], system identification [4], power system protection [5], image processing [6] and high voltage system [7] etc. There are two key mechanisms in ATS, back-

tracking mechanism (BT) to unlock the deadlock by moving backward to a visited solution and adaptive search radius mechanism (AR) to accelerate search speed by reducing search radius when the current cost is in a threshold. ATS Search radius (R) of ATS has been suggested in [2] that initial search radius should be in 20% - 60% range of search space and other setting parameters of ATS are also consulted [2]. There has been several approaches to enhance efficiency and performance of TS [8-9]. Until early 2011, modified adaptive tabu search (mATS) [10] was proposed to improve the performance of adaptive tabu search ATS by adding an adaptive neighborhood mechanism, namely AN. AN is normally invoked at the same time of AR. The steps of ATS algorithms can be summarized as follows:

STEP 0: Initialization

Generate an initial solution, neighborhood; set best solution, AC, TC, TL, (iteration) counter, search radius (R), Δ_i , δ_i and k^{th} backward.

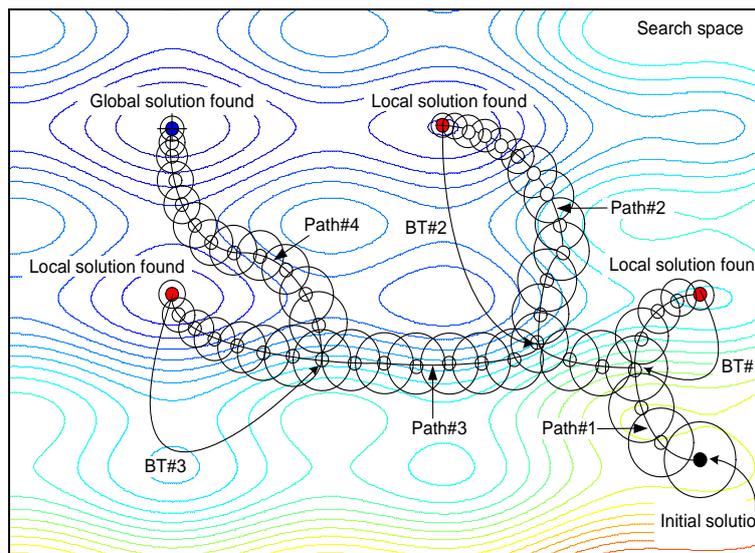


Fig. 1 Trace of the ATS with a fixed number of neighborhood members

STEP 1: Iteration

Generate search space and possible solutions in a neighborhood. Evaluate cost values for all solutions. If the current best solution has a lower cost than the best solution, replace the best solution by the current best and update the TL by tabuing the (previous) best solution, otherwise the best-solution remains unchanged and the current best solution becomes tabu instead. If the search has not been able to improve the best-solution for a certain time, go to *STEP 3*. Update counter.

STEP 2: Termination

Exit with the global optimum solution if the TC is (are) met, otherwise go to STEP 1.

STEP 3: AR and BT mechanisms

If deadlock occurs, invoke the BT mechanism. If the cost value of the current best solution is lower than the preset cost, invoke the AR mechanism. Update counter and go to STEP 1. (For more details see [2].)

3. Modified Adaptive Tabu Search Algorithms

Modified adaptive tabu search or mATS is proposed to improve ATS performance with Adaptive Neighborhood mechanism, namely AN. The mATS algorithms contain 3 steps of which steps 0, 1 and 2 are the same as these of the ATS. Step 3 of the mATS can be read as follows:

STEP 3: AR BT and AN mechanisms

If deadlock occurs, invoke the BT mechanism. If the cost value of the current best solution is lower than the preset cost, invoke the AR and AN mechanisms. Update counter and go to STEP 1.

The main concept of the proposed mATS based on AN is focusing on managing the number of neighborhood members. The tactic we applied is to increase the number of neighborhood members every time the AR is invoked. For example, an incremental number is 5; the first time the AR is called, the N member is increased from 30 to 35, and so on. The N member will not be increased endlessly because AN collaborates with AR and also concerns the current objective function value, J .

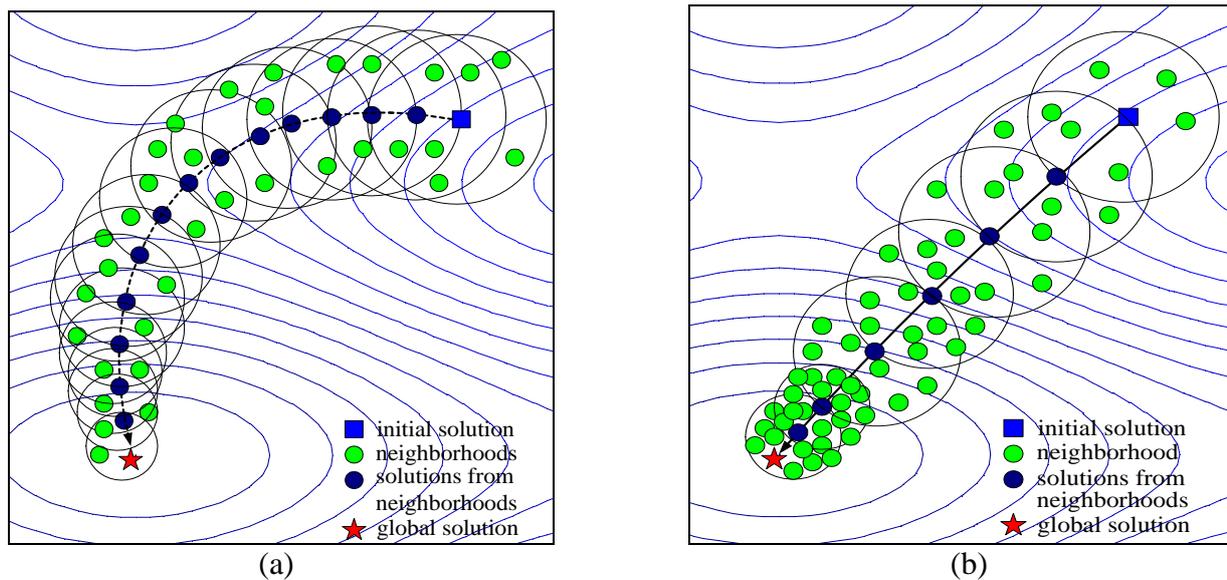


Fig. 2 Effect of number of neighborhoods to the straightforward direction to the global solution (a) ATS, $N=3$ and (b) mATS, $N=5$ (for example).

The aim to enhance performance of ATS via AN for the proposed mATS is to accelerate search speed to the near optimum while the right direction is still kept. Comparative demonstration is shown in Fig. 2. Fig. 2(a) demonstrates the trace of ATS without AN whose shape was not straightforward to the near optimum. On the contrary, in Fig. 2(b) the ATS with AN or mATS with increasing AN can go straightforward directly to the near optimum since its enough condensed number of neighbor can still keep the right direction until the near optimum is found.

Setting parameter AN of mATS has been suggested to select mATS-b (increasing type) because the easy problem can be solved simply by the original ATS and no need to do more, but some hard to solve problems can be probably solved by mATS-b than by the mATS-a because the mATS-b can reasonable keep the right search direction to local optimum. For deadlock phenomena in mATS task can be

handled by back-tracking mechanism (BT) by move backward the current solution to a previous one solution in tabu list for exploring new direction of the mATS that is why BT can release the mATS from a deadlock.

4. Computation Results

4.1 Performance Evaluations

Both mATS and ATS are coded in MATLAB™ and run on Laptop Intel® Celeron® M340 processor 1.5 GHz HDD 160 GBytes RAM 256 Mbytes. Three selected surface optimization problems are Bohachevsky’s function, Rastrigin’s function and Shekel’s foxholes function, namely BF, RF and SF, respectively. These surface functions are summarized in Table 1 and Table 2 is filled with the setting parameters of AR and AN used for testing.

Table 1 Test functions

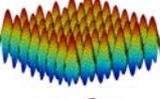
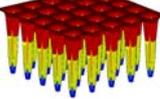
Surface names	Surface functions	Search spaces	Sketches
Bohachevsky	$f(x, y) = x^2 + 2y^2 - 0.3\cos(3\pi x) - 0.4\cos(4\pi y) + 0.7$	[-2, 2]	
Rastrigin	$f(x, y) = x^2 + y^2 - 10\cos(2\pi x) - 10\cos(2\pi y) + 20$	[-2, 2]	
Shekel's foxholes	$f(x_1, x_2) = \left[\frac{1}{500} + \sum_{j=1}^{25} \frac{1}{j + \sum_{i=1}^2 (x_i - a_{ij})^6} \right]^{-1}$ where $a_{ij} = \begin{pmatrix} -32 & -16 & 0 & 16 & 32 & -32 & \dots & 0 & 16 & 32 \\ -32 & -32 & -32 & -32 & -32 & -16 & \dots & 32 & 32 & 32 \end{pmatrix}$	[-40, 40]	

Table 2 Setting parameters of mATS for three test functions

Functions	BF		RF		SF	
	AR	AN	AR	AN	AR	AN
Initialization	R=0.2	N=30	R=0.2	N=30	R=0.8	N=30
1 st stage	R=2×10 ⁻³ (if J ≤ 0.1)	N=35 (if J ≤ 0.1)	R=2×10 ⁻³ (if J ≤ 0.1)	N=35 (if J ≤ 0.1)	R=2×10 ⁻³ (if J ≤ 0.1)	N=35 (if J ≤ 5)
2 nd stage	R=2×10 ⁻⁴ (if J ≤ 0.001)	N=40 (if J ≤ 0.001)	R=2×10 ⁻⁴ (if J ≤ 0.001)	N=40 (if J ≤ 0.001)	R=2×10 ⁻⁴ (if J ≤ 0.001)	N=40 (if J ≤ 2)

All these problems are searched 20 trials and results then obtained by averaging in Table 3 for averaged search time, and Table 4 for averaged search round, respectively. Percents of speed up ratios of mATS with respect to ATS are summarized by Fig.3 obtained easily by the equation (1).

$$Speed\ up\ ratios\ (\%) = \left(\frac{T_{ATS} - T_{mATS}}{T_{ATS}} \right) \times 100 \quad (1)$$

Where T_{ATS} and T_{mATS} stand for averaged search time of ATS and modified ATS, respectively.

Table 3 Averaged search time (seconds)

	TEST FUNCTIONS		
	BF	RF	SF
ATS	2.9813	3.4986	0.9448
mATS	2.4540	3.2397	0.8943

Table 4 Averaged search round (iterations)

	TEST FUNCTIONS		
	BF	RF	SF
ATS	657.80	833.50	77.55
mATS	481.75	732.85	62.75

Fig. 3 shows that mATS can do the best on BF surface with the 17.69% speed up ratios. For RF and SF surfaces, the speed up ratios are 7.40% and 5.35%, respectively.

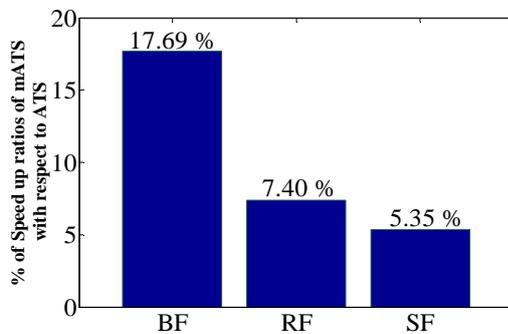


Fig. 3 Percents of speedup ratios of mATS wrt. ATS

4.2 Application to frequency modulation sounds (FMS)

Parameter identification problem of frequency modulation sounds (FMS) is to a highly complex multimodal optimization. The aim of solving this problem is to minimize the error between evolved data and model data. The classic genetic algorithm (GA) and its modified forms [9-10], have previously been applied on the FMS problem.

The problem is to specify six parameters, of the FMS model represented in equation (2)

$$y(t) = a_1 \sin(\omega_1 t \theta + a_2 \sin(\omega_2 t \theta + a_3 \sin(\omega_3 t \theta))) \quad (2)$$

where $\theta = 2\pi / 100$. The objective function is defined as the summation of square errors between the evolved data and the model data as follows:

$$J(a_1, \omega_1, a_2, \omega_2, a_3, \omega_3) = \sum_{t=0}^{100} [y(t) - y_0(t)]^2 \quad (3)$$

and the model data are given by the following equation,

$$y_0(t) = 1.0 \sin(5.0t\theta + 1.5 \sin(4.8t\theta + 2.0 \sin(4.9t\theta))) \quad (4)$$

All seeking search parameters, $(a_1, \omega_1, a_2, \omega_2, a_3, \omega_3)$ are limited in the same range -6.4 to 6.35 and the setting key parameters is shown in Table 5.

Table 5 Setting parameters of AR and AN of mATS for FMS

Parameters	AR	AN
Initialization	R=1.0	N=30
1 st stage (if $J \leq 25$)	R=0.2	N=35
2 nd stage (if $J \leq 23$)	R=0.002	N=40
3 rd stage (if $J \leq 20$)	R= 2×10^{-4}	N=45
4 th stage (if $J \leq 12$)	R= 2×10^{-6}	N=50
5 th stage (if $J \leq 0.01$)	R= 2×10^{-7}	N=50

The program was developed using MATLAB and run on an 1.6 GHz AMD CPU with 1 GB RAM and 60 GB HDD. The global minimum of the objective function for this problem has the about zero, $J(x^*)=0$. After many trials, mATS can obtain the optimal solution under the requirement, $J < 1.003 \times 10^{-4}$. For this successful run, CPU has completely spent 1256.2 seconds with 25,326 iterations as show with the convergence curve in Fig. 4.

Fig.5 shows the initial solution, $(a_1, \omega_1, a_2, \omega_2, a_3, \omega_3) = (-0.1527, 3.0854, -5.7232, 4.6297, 2.7527, -5.5446)$ at the

beginning with its objective function $J=33.1042$. Another figure shows the optimal solution after searching by the efficient mATS. The optimal solution is $(-0.9981, -5.0002, 1.5009, 4.7999, -1.9996, -4.9000)$ with $J=1.0023 \times 10^{-4}$. Comparison with the previous work [10] on the quality of the best solution, mATS has obtained the better solution $J=1.0023 \times 10^{-4}$ than of the modified GA ($J \approx 0.6$).

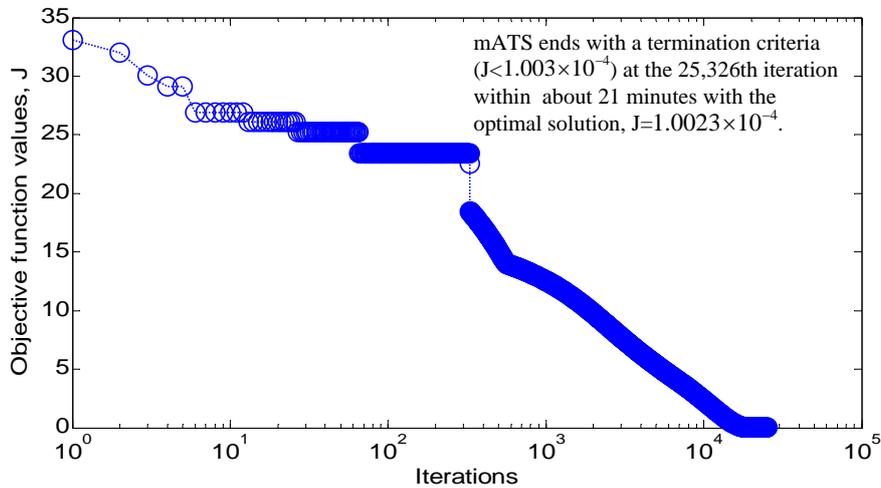


Fig. 4 Convergence curves of mATS on the FMS problem

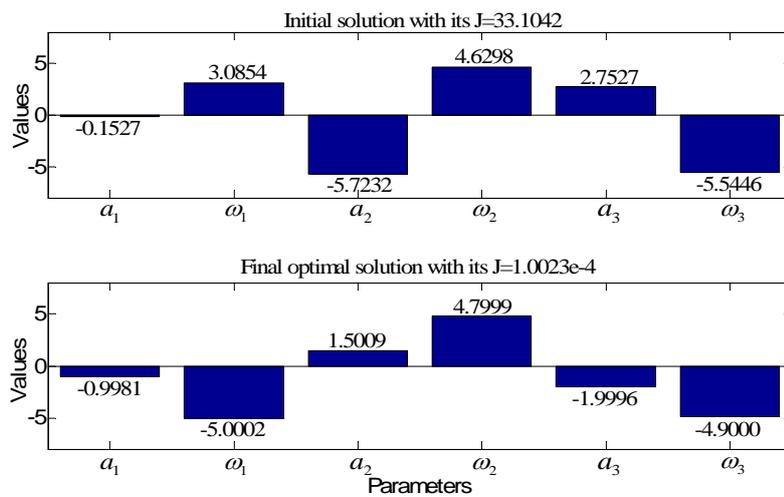


Fig. 5 Initial solution and searched optimal solution from the proposed mATS algorithms

5. Conclusion

In this paper, mATS has been proposed, by adding an adaptive neighborhood member mechanism to the original ATS. From the computational tests, the mATS can do well with the three surface optimization problems, BF, RF and SF, and the corresponding searches are faster than ATS by 5.35%-17.69 %. mATS is also applicable for any real world problem solving such as the parameter identification problem of frequency modulation sounds system. The mATS algorithm, with adaptive neighborhood mechanism has been demonstrated to have a superior feature on high-quality solutions. Convergence property of mATS on FMS problem is also confirmed. The results show that the proposed method was indeed capable of obtaining higher quality solution efficiently in FMS problems.

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NOTATION LISTS

Δ_i : preset cost value

δ_i : scaling factor of AR mechanism

k^{th} : previous solution at backward k order

AC: aspiration criteria

AN: adaptive neighborhood member mechanism

AR: adaptive search radius mechanism

ATS: adaptive tabu search algorithm

BF: bohachevsky's function

BT: back-tracking mechanism

FMS: frequency modulation sounds system

mATS: modified adaptive tabu search algorithm

R: search radius

RF: rastrigin's function

SF: shekel's foxholes function

T_{ATS} : averaged search time of ATS

T_{mATS} : averaged search time of mATS

TC: termination criteria

TL: tabu list

TS: tabu search algorithm

References

- [1] F. Glover and M. Laguna, "Tabu Search", Kluwer Academic Publisher, 1989.
- [2] S. Sujitjorn, T. Kulworawanichpong and D. Puangdownreong, "Adaptive Tabu Search and Applications in Engineering Design", Book Chapter in Integrated Intelligent system for Engineering Design (ed.X.F Zha and R.J. Howlett), IOS Press, The Netherlands, 2006 , pp. 233-257.
- [3] D. Puangdownreong, T. Kulworawanichpong and S.Sujitjorn, "Input Weighting Optimization for PID Controllers based on the Adaptive Tabu Search", Proceeding of IEEE TENCON 2004, Chiang Mai, Thailand, 2004, pp. 451-454.
- [4] T. Kulworawanichpong, K.L. Areerak, K.N. Areerak and S.Sujitjorn, "Harmonic Identification for Active Power Filters via Adaptive Tabu Search", Lecture Notes in Artificial Intelligences, LNAI 3215 Part I, 2004, pp. 687-694.
- [5] K.N. Areerak, T. Kulworawanichpong, and S.Sujitjorn, "Moving toward a new era of intelligent protection through digital relaying in systems", Lecture Notes in Artificial Intelligences, LNAI 3215 Part I, 2004, pp. 1255-1261.
- [6] N. Sriyingyong, and T. Kulworawanichpong, "Wavelet-based Audio Watermarking using Adaptive Tabu Search", Proceeding of the 1st International

- Symposium on Wireless Pervasive Computing (ISWPC2006), Phuket, Thailand, 2006, pp. 1-5.
- [7] A. Oonsivilai and B. Marungsri, “Application of Artificial Techniques for Partial Discharges Localization in Oil Insulating Transformer”, WSEAS Trans. on System 7, 2008, pp. 920-927.
- [8] J. Kluabwang, D. Puangdownreong and S. Sujitjorn, “Performance Assessment of Search Management Agent under Asymmetrical Problems and Control Design Applications”, WSEAS Trans. on Computer 8, 2009, pp. 691-704.
- [9] J. Kluabwang and S. Sujitjorn, “Tabu Search: Its Modified Form and Management Agent”, Recent Patents on Electrical Engineering 2, 2009, pp. 135-145.
- [10] J. Kluabwang and S. Sujitjorn, “Modified Adaptive Tabu Search”, Proceeding of the 1st International Conference on Information Systems and Computational Intelligence (ICISCI 2011), Harbin, China, 2011, pp. 222-224.