Bat-Inspired Optimization Approach Applied to Jiles-Atherton Hysteresis Parameters Tuning

Leandro dos Santos Coelho
Industrial and Systems Eng. Grad. Program, Pontifical Catholic University of Parana, and Electrical Engineering, Federal University of Parana, Curitiba, PR, Brazil
leandro.coelho@pucpr.br

Viviana Cocco Mariani
Mechanical Eng. Grad. Program, Pontifical Catholic University of Parana, and Electrical Engineering, Federal University of Parana, Curitiba, PR, Brazil
viviana.mariani@pucpr.br

Helon Vicente Hultmann Ayala
Industrial and Systems Eng. Graduate Program (PPGEPS), Pontifical Catholic University of Parana (PUCPR), Curitiba, PR, Brazil
helonayala@gmail.com

Andre Mendes da Silva
Mechatronics Eng. Undergraduate Program, Pontifical Catholic University of Parana, Curitiba, PR, Brazil
andremendes1991@gmail.com

Nelson Jhoe Batistela
GRUCAD-EEL-CTC, Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil
jhoe@grucad.ufsc.br

Jean Vianei Leite
GRUCAD-EEL-CTC, Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil
jean@grucad.ufsc.br

ABSTRACT
Recently, it was proposed a new metaheuristic optimization approach namely bat algorithm (BA), which is based on the fascinating capability of microbats in to find their prey and discriminate different types of insects even in complete darkness. In this paper, we introduce a novel enhanced hybrid approach combining BA with a mutation style operator from differential evolution and beta probability distribution (BADEBD) and report its performance on to identification of the 10 hysteresis parameters for the 2-dimensional Jiles-Atherton hysteresis modeling to a material under rotational excitation. Compared with the classical BA, the proposed BADEBD performs better in terms of the solution accuracy and the convergence rate.

Categories and Subject Descriptors
G.1.6 [**Mathematics of Computing**]: Optimization—*Global Optimization*; I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search—*Heuristic methods*

Keywords
Bat Algorithm; Differential Evolution, Hysteresis Parameters

1. INTRODUCTION
A promising recent paradigm is the bat algorithm (BA) proposed by Yang [1], which is based on the fascinating capability of microbats in to find their prey and discriminate different types of insects even in complete darkness based on echolocation features. On the other hand, differential evolution (DE) [2] is arguably one of the most powerful stochastic real-parameter optimization algorithms of current interest. This paper suggests a novel combination of BA with a mutation style operator from DE and beta probability distribution (BADEBD) for Jiles-Atherton (J-A) hysteresis model parameters estimation of a material under rotational excitation. Results show the potential of the BADEBD as an efficient search technique for optimization of J-A hysteresis parameters.

GECCO'14, July 12–16, 2014, Vancouver, BC, Canada.
ACM 978-1-4503-2662-9/14/07.

The rest of this manuscript is structured as follows. Section 2 provides an overview of the BA and BADEBD. The performance of the optimization algorithms for the J-A hysteresis modeling is presented in Section 3 while Section 4 concludes the paper with final remarks.

2. BAT ALGORITHM
Bats have been known to be mysterious creatures that exhibit an interesting ability to navigate their environments and capture preys without relying on their eyesight by using the echolocation technique. BA is inspired from the echolocation of microbats and the its basic procedure involves the following steps [1]:

Step 1: Initialize the bat population, where for each bat (i), its position x_i^t and velocity v_i^t in a d-dimensional search space should be initialized;

Step 2: Define the pulse frequency F_i at x_i^t ;

Step 3: Initialize the pulse rates r_i^t and the loudness A_i^t ;

Step 4: Generate new solutions by adjusting frequency, and updating velocities and locations/solutions;

Step 5: Evaluate the objective function of the bat population;

Step 6: Rank the bats and find the current best x^*;

Step 7: Repeat *Steps 4-6* until a given stopping criterion related to the number of objective function evaluations is reached.

The adopted equations in the *Steps* 1 to 7 are given by [3]:

$$F_i = F_{\min} + \left(F_{\max} - F_{\min}\right)\cdot \beta \tag{1}$$

$$v_i^t = v_i^{t-1} + \left(x^* - x_i^{t-1}\right) \tag{2}$$

$$x_i^t = x_i^{t-1} + v_i^t \tag{3}$$

$$x_{i,new}^t = x_{i,old}^{t-1} + \varepsilon \cdot \left\langle A_i^{t-1} \right\rangle \tag{4}$$

$$A_i^t = \alpha \cdot A_i^{t-1}, r_i^t = r_i^0 \cdot \left(1 - e^{-\gamma t}\right) \tag{5}$$

where $\beta \in [0,1]$, $r \in [0,1]$ and $\varepsilon \in [-1,1]$ are random vectors drawn from uniform distribution. F_i is the i^{th} bat emission frequency, F_{min} and F_{max} the frequency´s lower and upon bounds respectively. v_i^t is the i^{th} bat velocity vector at the iteration t, x_i^t the i^{th} bat position vector at the i^{th} iteration. Besides, $x_{i,old}^t$ is the same of x_i^t in equation (3), but after the use of (4), it is stored in the same memory position but denoted, as $x_{i,new}^t$. Finally, α and γ are parameters to be set before the run. In this work, their values are assigned to 0.9, for both cases.

On the other hand, to improve the performance of classical BA by balancing the exploration and exploitation, in the proposed BADEBD, we have induced a DE's mutation operator [2] in the *Step 4* of the traditional BA instead of the utilization of velocity v_i in each bat. Mutation operation integrated in the BADEBD is carried out by the arithmetical combinations of the selected bats, but using a mutation rate generated by a beta distribution in range [0,1]. The mutation operation is a powerful strategy to diversify the bats population and improve the BADEBD's performance to avoid the premature convergence.

3. OPTIMIZATION RESULTS

In order to solve the optimization problem, the vector J-A model is considered in its two-dimensional version (*x*,*y*) so it is necessary 10 parameters (five for the transverse and five for the rolling direction) for the modelling of an anisotropic material: saturation magnetization M_S, parameters *a* and α related to the anhysteretic Langevin function, *c* related to the reversible magnetization and *k* related to the irreversible magnetization. Experimental data, obtained from a Rotational Single Sheet Tester (RSST) [4] are used in the curve fitting. In this paper, it is adopted in the optimization procedure the minimization of an objective function *F* given by the sum of the Mean Squared Errors (MSE) between calculated and measured curves in the two-dimensional version (*x*,*y*), i.e., $F = \text{MSE}x + \text{MSE}y$.

We adopted the following control parameters for tested BA and BADEBD: number of independent runs is 30, the population size is 25 bats, the maximum of generations is equal to 300. In the setup of the BA is adopted both loudness and pulse rate equal to 0.5. In the BADEBD approach, both loudness and pulse rate are generated with uniform distribution in range [0,1].

Table 1 presents the simulation results of objective function *F* of best solution after 7,500 objective function evaluations (in 30 runs). A result with Boldface means the best value found in Table 1. Fig. 1 showed measured and calculated curves with the best J-A parameters set in terms of *F* value obtained using BADEBD. Furthermore, Table 2 shows the obtained J-A model parameters. In terms of mean and minimum *F* values, the BADEBD found best values than the tested traditional BA. The best solution of the BADEBD was with *F*=4422.8 (MSE*x*=784.6 and MSE*y*=3638.2) with error between experimental and calculated losses of 1.49%. The results of the J-A hysteresis model with BADEBD are found to be in good agreement with the measured ones. Through the application of the BADEBD was revealed promising to obtain an optimized parameters set for the J-A vector hysteresis model.

Table 1. Optimization results of *F* for the J-A model

Optimization Method	Objective function *F* of best solution (bat)			
	Maximum (Worst)	Mean	Minimum (Best)	Std. Dev.
Classical BA	8908.4	6373.2	5089.6	1497.3
BADEBD	5564.3	**4824.7**	**4422.8**	411.5

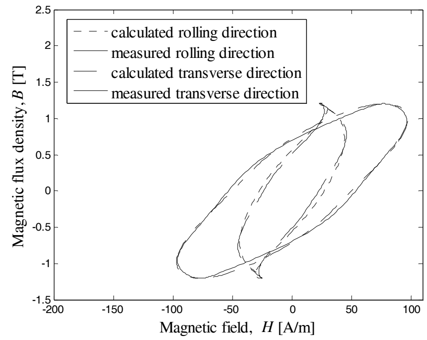

Figure 1. Calculated (solution of BADEBD) and measured *B-H* curves for the material under rotational excitation.

Table 2. Parameters for the J-A model obtained by BADEBD

Variable	Rolling direction (*x*)	Transverse direction (*y*)
M_S	1.390×10^6 [A/m]	2.498×10^6 [A/m]
k	3.399×10^1 [A/m]	5.556×10^1 [A/m]
c	2.050×10^{-1}	9.500×10^{-2}
a	8.467×10^1 [A/m]	2.477×10^2 [A/m]
α	2.609×10^{-4}	2.480×10^{-4}

4. CONCLUSION AND FUTURE WORK

In this paper, the proposed BADEBD algorithm has been successfully implemented to solve a J-A modeling problem. Simulation results have shown significant solutions for the proposed BADEBD in the case of J-A hysteresis model parameters estimation for the RSST when compared with the classical BA. In the future work the proposed BADEBD will be applied to benchmark optimization problems and practical applications such as transformers design optimization.

5. REFERENCES

[1] X. S. Yang, 2010. A new bat-inspired algorithm, In *Nature Inspired Cooperative Strategies for Optimization (NICSO)*, Springer, Studies in Computational Intelligence, 284:65-74.

[2] R. Storn and K. V. Price, 1995. Differential evolution - A simple and efficient adaptive scheme for global optimization over continuous spaces, *Technical Report TR-95-012*, International Computer Science Inst., Berkeley, CA, USA.

[3] T. C. Bora, L. S. Coelho and L. Lebensztain, 2012. Bat-inspired optimization for the brushless DC wheel motor problem, *IEEE Transactions on Magnetics*, 48(2):947-950.

[4] P. A. da Silva Jr, 2007. Workbench for assays of ferromagnetic materials in single sheet under rotational fields, PhD Thesis (in Portuguese), Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil.