Application of ant colony optimization algorithm to the thermal parameter estimation of modern electronic structures

T. Raszkowski, A. Samson, M. Zubert, M. Janicki, A. Napieralski

Department of Microelectronics and Computer Science,
Lodz University of Technology, DMCS-TUL
ul. Wolczanska 221/223, 90-924 Lodz, Poland, traszk@dmcs.p.lodz.pl

ABSTRACT

The proper estimation of the thermal model parameters is one of the most important research area. One of these parameters is heat transfer coefficient which has got the big influence on the temperature of the electronic structures. Due to this fact, the paper focuses on the determination this coefficient. In order to obtain its value the ant colony optimization algorithm was employed. The analysis are based on the real data.

Keywords: Ant colony algorithm, heat transfer coefficient, heat equation, thermal model, modern electronic structures

1 INTRODUCTION

The modelling of the heat transfer parameters is a very important issue and the crucial aspect of the proper operating of every modern electronic structure and device. Therefore, the accurate estimation of all thermal parameters may contribute to further optimization of such structures and significant improvement on their reliability. One of that kind of thermal parameters, which is needed to be estimated, is the heat transfer coefficient [1], [2]. Estimation of this parameter is extremely difficult to prepare due to the fact that the analyzed heat transfer coefficient strongly depends on the dimensions and the shape of the investigated structure as well as the temperature of the structure surface and the external environment [3], [4]. Due to this fact, the extraordinarily important issue is the choice of possibly the best method which helps obtaining the satisfying results.

The significant number of the electronic system failures or malfunctions of electronic devices are caused by the thermal reasons. Thus, there is a need for an accurate estimation of the temperature of the structure. The determination of the heat transfer coefficient, mentioned previously, is one of the crucial steps to proper analysis of the thermal phenomena occurred in the investigated strucure. The value of the mentioned coefficient expresses the radiation as well as the heat convection.

The presented problem is particularly discussed in this paper. Simulations are based on the real measurements of the temperature responses of the silicon carbide diode which is placed in a TO-220 package. Moreover, the measured values of the thermal resistances are related to the device internal structure. Apart from that, the mathematical model of thermal dependences, including the average heat transfer coefficient value depending on the surface temperature is employed. Then, the description of the ant colony optimization algorithm, employed to the estimation of the heat transfer coefficient, is presented. The simulation results are also presented and carefully discussed.

2 THE ANT COLONY OPTIMIZATION ALGORITHM

The classical ant colony optimization algorithm was proposed in 1992 by M. Dorido [5], [6]. This algorithm is based on the probabilistic techniques which help solving the complicated problems related to finding good or the best solutions from among a big number of possibilities. The algorithm was constructed based on the observation of ant colony behaviour. The single ants search the path between the food source and their anthill. When the food is found by the ant, it goes back to the colony and leaves the trace in the form of the pheromones. These pheromones are signs for other ants to change their orientation and to more effective searching of the food. With the passing of the time, the pheromones vaporise, so their influence on other ants are getting weak. On the other hand, on paths which are used by many ants the amount of the pheromones increases. This situation encourages them to follow the such paths. This kind of the communication between ants helps them to construct the optimal way from the colony to the point where the food is placed.

From the mathematical point of view, the problem presents itsefl in the following way. Firstly, the start point, corresponding to the anthill, is chosen. Secondly, the single

ant assigns objects to its present location according to the probability which is given by the following formula:

$$p_{ij}^{k}(t)=\frac{(\tau_{ij}(t))^{\alpha}\cdot(\eta_{ij})^{\beta}}{\sum_{l\in N_i^k}(\tau_{ij}(t))^{\alpha}\cdot(\eta_{ij})^{\beta}} \quad (1)$$

where $j\in N_i^k$. Variables and constants used in the formula (1) have the meanings presented below. The matrix τ_{ij} includes the pheromone traces placed on paths between the ith and j^{th} nodes. The t corresponds to the number of the iteration of the algorithm, so it indicates the length of the distance which was travelled by the ant k. The η_{ij} expresses usually the distance between the ith and j^{th} nodes. The constant α controls the weight of the pheromone. Usually, the constant α is a real number from the interval $(0;1)$, however it is also possible taking any non-negative value of this parameter. On the other hand, the parameter β, being a weight of the heuristic values, expresses the relative influence of the heuristic information on the decision about the choice of possible way taken by the ant. It is generally assumed that the value of the parameter β is equal or greater than the unity. The set N_i^k specifies the neighborhood of the present location of the kth ant, denote by node i. The mentioned set collects the information about nodes which surrounds the node in which the ant is present. Elements of the set N_i^k are denote as j. It is worth saying that classical ant colony algorithm allows movement towards the free surrounding nodes only. It means that if another ant occupies the neighboring node j, the investigated ant is not allowed to travel there.

As it was mentioned earlier, with the passing of the time, the intensity of the pheromones placed by the ant weaks. Due to this fact, in the next iteration, when all ants undertake the decision and take steps, there is a need for updating the pheromone traces. It is accomplished using the following expression:

$$\tau_{ij}(t+1)=\rho\tau_{ij}(t)+\sum_{k=1}^{m}\Delta\tau_{ij}^{k} \quad (2)$$

where m denotes the total number of ants in the investigated area. The ρ parameter, $\rho\in(0;1)$, is known as the pheromone vaporising coefficient. On the other hand, the parameter $\Delta\tau_{ij}^{k}$ reflects the dependence between the ith and j^{th} nodes. When the object i corresponds to the location j, the value of the mentioned parameter is determined by the ratio of the value of the pheromone Q placed by the ant to the value of the objective function J^k specified for the kth ant. When the object i and the location j are not in assigned to each other, the value of the $\Delta\tau_{ij}^{k}$ parameter is equal to zero. It can be expressed in the following symbolic notation:

$$\Delta\tau_{ij}^{k}=\begin{cases}\dfrac{Q}{J^k}, & \text{when } i \text{ corresponds to the location } j\\ 0, & \text{in other case}\end{cases} \quad (3)$$

The algorithm is stopped after a fixed number of steps or when the lowest value of the objective function is found.

3 SIMULATIONS AND RESULTS

The algorithm, presented in the previous section of this paper, was to obtain the approximating formula which allows calculating the value of the heat transfer coefficient. The explicit mathematical formula makes the determination of this coefficient easier because it requires the values of the temperature differences between the surface of the investigated structure and its ambient. Thus, it can be commonly used without the specific equipment and the laboratory conditions. The mentioned approximation can be prepared using the following formula [7]:

$$h=a\cdot\Delta T^{b}+c \quad (4)$$

where h is the heat transfer coefficient, ΔT denotes the differences between structure temperature and the ambient, while a, b and c are constants which have to be found. It is worth saying that the formula (4) do not include the information about any cooling conditions. It means that the lack of the forced convection is assumed and the radiation and the natural convection are considered. Thus, the following formula is taken into considerations:

$$h=h_r+h_{nc} \quad (5)$$

where h_r expresses the value of the heat transfer coefficient connected to the radiation and h_{nc} means its value related to the natural convection phenomenon.

TABLE I. START POINT COORDINATES

Parameter symbol	a_0	b_0	c_0
Parameter value	2.10	0.50	3.50

In order to determine the values of the constants a , b and c, empirical values of the heat transfer coefficient were needed. They were obtained using mathematical formulas presented in [8], [9]. Then, the objective function J was established. It is determined in the following way:

$$J = \sum_{j=1}^{n} \left(h_j - \left(a \cdot \Delta T^b + c \right) \right)^2 \tag{6}$$

Due to the fact that three different constants need to be estimated, the three-dimensional discretization mesh was constructed using one hundred nodes in each dimension. Thus, the total number of discretization nodes is equal to one million. Moreover, the distances between nodes in each dimension are the same.

Then, the start point was chosen. Its coordinates are presented in TABLE I. Moreover, values of all needed parameters used in algorithm have been fixed. The TABLE II. demonstrates the mentioned parameters values.

TABLE II. ANT COLONY OPTIMIZATION ALGORITHM PARAMETERS VALUES

Parameter	Parameter value
α	**0.5**
β	**5**
τ_{start}	**10^{-5}**
η	**0.01**
Q	**1**
ρ	**0.1**
m	**20**
Number of iterations	**10^4**

The Fig. 1. presents the distance travelled by the ant which reaches the most optimal location in the shortest time. As it can be seen in this figure, the start and the end position are marked by the green and the red dot, respectively. The marked distance was travelled in 176 iterations of the algorithm.

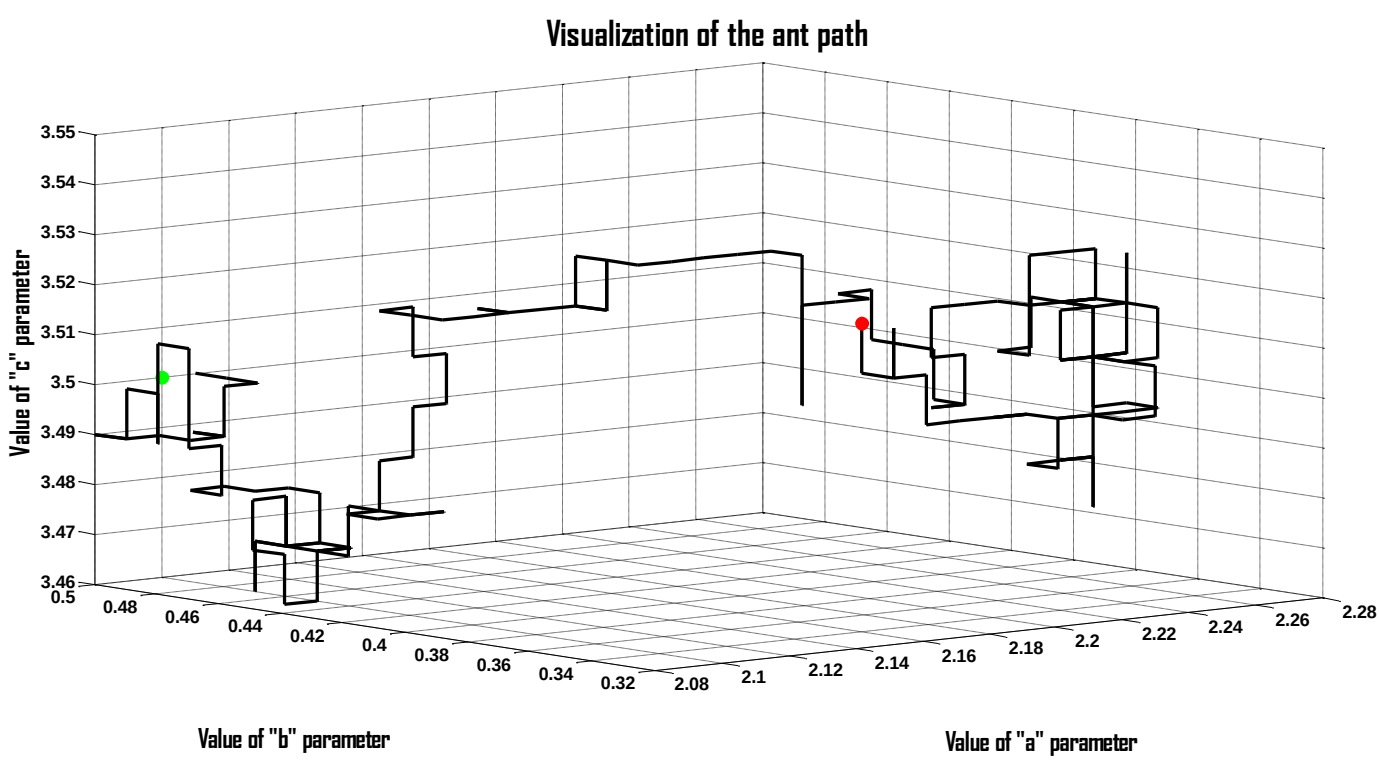

Fig. 1. Visualization of the ant path

TABLE III. END POINT COORDINATES

Parameter symbol	a	b	c
Parameter value	2.17	0.35	3.52

The TABLE III. demonstrates the coordinates of the end point of ant path. Thus, the heat transfer coefficient can be estimated using the following formula:

$$h = 2.17 \cdot \Delta T^{0.35} + 3.52 \quad (7)$$

The goodness of the estimation is confirmed by the fitting to the measured data and the calculated heat transfer coefficient values. The value of the R^2 coefficient is equal to 0.99 what proves the high quality of the parameter approximation. The graphical visualization of the mentioned fitting is shown in Fig. 2.

4 CONCLUSIONS

This paper presents the usage of the ant colony optimization algorithm in the determination of the heat transfer coefficient values. Presented analysis is based on the real data. The high accuracy of the fitting is proven by the R^2 coefficient which value is almost equal to the unity.

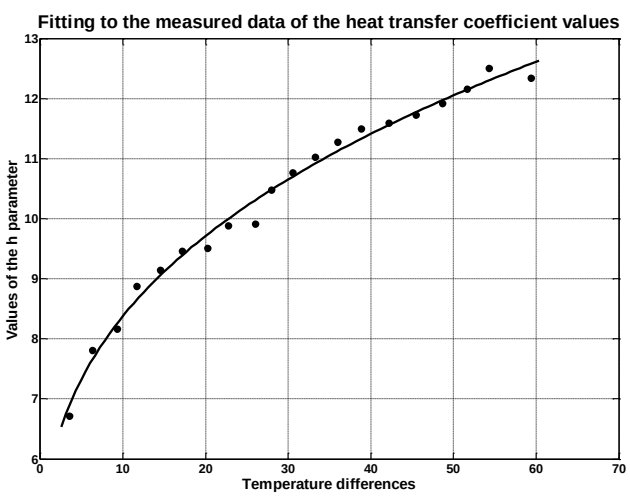

Fig. 2. Fitting to the measured data of the heat transfer coefficient values

ACKNOWLEDGMENTS

This research was supported by the National Science Centre projects 2013/11/B/ST7/01678 and 2013/09/N/ST7/04069.

REFERENCES

[1] M. Zubert, G. J. Anders, A. Napieralski, A. Skorek: Rating of Pipe-Type Cables with Slow Circulation of Dielectric Fluid. IEEE Transactions on Industry Applications, 43(5):1164–1171, 2007.

[2] M. Janicki, A. Samson, T. Raszkowski, M. Zubert, A. Napieralski, Comparison of Green's function solutions for different heat conduction models in electronic nanostructures, Microelectronics Journal (2015), http:// dx.doi.org/10.1016/j.mejo.2015.07.008, pp. 1-5, ISSN: 0026-2692

[3] C. Koerner, H.W. Bergmann, 'The physical defects of the hyperbolic heat conduction equation', Applied Physics A: Materials Science & Processing, vol. 67, pp. 397-401, 1998.

[4] D.W. Tang, N. Araki, 'Analytical solution of non-fourier temperature response in a finite medium under laser-pulse heating', Heat and Mass Transfer, vol. 31, pp. 359-363, 1996.

[5] A. Colorni, M. Dorigo et V. Maniezzo, 'Distributed Optimization by Ant Colonies', Elsevier Publishing, 134-142, 1991.

[6] M. Dorigo, Optimization, Learning and Natural Algorithms, PhD thesis, Politecnico di Milano, Italy, 1992.

[7] M. Janicki, P. Kawka, O. Leon, G. De Mey, A. Napieralski, "Investigation of Circuit Forced Convection Air Cooling in Low Speed Wind Tunnel", Proc. 7th Intl. Workshop THERMINIC, 24-27 September 2001, Paris, France, pp. 79-82.

[8] A. Samson, M. Janicki, T. Raszkowski, M. Zubert, "Determination of Average Heat Transfer Coefficient Value in Compact Thermal Model", unpublished

[9] T. Raszkowski, A. Samson, T. Torzewicz, M. Janicki, M. Zubert, M. Felczak, "Estimation of Average Convective of Heat Transfer Coefficient in Electronic Systems", unpublished