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Predictive Placement of IC Chips using ANN-GA Approach for Efficient Thermal Cooling

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ABSTRACT

In this research, numerical modelling is used to explore the heat transfer through natural convection capabilities of nine aluminum integrated circuit chips that are installed on substrate board. The goal is to figure out where on the substrate board these IC chips would be best placed if they were arranged differently. The dimensionless parameter (λ) plays a very essential role, and by applying a hybrid technique consisting of ANN and GA. ANSYS Icepack calculates IC chip temperature distributions in 3D steady state numerical simulations. It has been shown that the form, dimensions, and IC chips' substrate board positioning affects their operating temperature. In comparison to the strategies that have been used in the past, hybrid optimization is the strategy that has shown to be the most reliable in properly predicting how the IC chips would be arranged on the substrate board. It has been observed that higher values of one of these parameters lead to a reduction in the maximum temperature surplus. A correlation has been established to illustrate this relationship as it increases. The most favorable simulation outcomes are utilized to drive a genetic algorithm (GA), which identifies the optimal configuration ensuring that the temperatures of the heat sources remain well below their specified maximum operating conditions, as outlined in the data sheets. The maximum temperature variation between the lowest and highest extreme configurations ranges between 4 - 8%. The smallest size IC chip, U2 with high heat dissipation rate attains the maximum temperature in the configuration, however, the temperature variation for the low powered IC chips U3, U4 and U7 are very small. Found good agreement of both the data with an error band of 10%, and thus confirms the accuracy of the network.

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1. Introduction

Ramadhyani *et al.,* [1] computational research of conjugate heat transfer from tiny isothermal heat sources buried in a large substrate discovered that heat transmission is affected by the substrate's thermal conductivity compared to the fluids. Faghri *et al.,* [2] computed turbulent flow in heated rectangular blocks. High Reynolds number emerging flow employs a modified Lam-Bremhorst turbulence model. Duct entry length reduces heat source leading edge pressure drop. Culham *et al.,* [3] used Microelectronic Thermal Analyzer to anticipate local chip temperatures using a numerically linked fluid-solid model with arbitrarily positioned heat sources. Chen and Liu [4] optimised forced convection arrangement of 9 heat sources. Center-to-center location optimises heat transfer. Chuang *et al.,* [5] numerically simulated heat transfer in five places using PHOENICS. For all configurations, including vertical, top heat sources had the highest temperature. Furukawa and Yang [6] used SIMPLER numerical approach to solve the governing equations and found that increasing thermal conductivity via board thickness cools chips and maximises heat transfer at chip surfaces. Yadav and Kant [7] used the k-E model to study how the size of the array and the temperature of the substrate affect the rate of heat transfer from a heated module. Hotta *et al.,* [8] found that surface radiation cools discrete heat sources under NC. Hotta and Venkateshan [9] discovered that ANN-GA was more significant. Hotta *et al.,* [10] found that painting discrete heat sources black enhances heat transport and decreases temperature by 15%. Natural and mixed convection heat transfer from five heat sources of varying sizes mounted on a PCB in a vertical channel were evaluated by Hotta and Venkateshan [11], who decided that the channel's highest-heating sources should be towards the bottom. Optimized passive cooling was achieved by Baudoin *et al.,* [12] of a source array was flush-mounted on a vertical plate by natural convection and found that vertical spacing must be nearly double horizontal spacing. The ideal arrangement depends on heat source density. The staggered configuration that was developed by Baudoin *et al.,* [13] was the result of mathematically optimising the location of a large number of power electronics components that were cooled. Durgam *et al.,* [14] optimised rectangular heat sources on a PCB board using COMSOL MULTIPHYSICS. Kurhade *et al.,* [15-18] studied numerical study of PCM cooling for smart-phone and thermal performance. Patil *et al.,* [19] and Waware *et al.,* [20] provide critical reviews on heat transfer and Heat Transfer Enhancement in Tubular Heat Exchangers with Jet Impingement. Rahul *et al.,* [21-25] explain the investigation on Laser Welding Parameters on the Strength of TRIP Steel. Gadekar *et al.,* [26], Kamble *et al.,* [27], and Gadekar and Kamble [28] explained experimental study on gear EP lubricant mixed with $Al_2O_3/SiO_2/ZrO_2$ composite additives to design a predictive system. Patil *et al.,* [29] used a water-based Al_2O_3 nanofluid was used in this work to grind materials due to its outstanding convective heat transfer and thermal conductivity qualities.

None of the studies examined a realistic approach of all electrical components and solved numerically using ANSYS Icepak's object-based modelling. In power conversion systems of switch mode power supply, heat source positioning must be optimised. This study uses ANSYS Icepak to analyse NC heat transfer of nine protrusion (Aluminium) installed on a PCB board (FR-4) and uses a rapid hybrid optimization process that combines ANN and GA to discover their best configuration. The Nine non-identical protrude-mounted heat sources are evaluated from the data sheets available at the manufactures catalog. Datasheets show heat source sizes and heat provided for maximum working temperatures. Table 1 specifies all components.

Table 1
Specification of Heat source configuration

EC	L (mm)	W (mm)	H (mm)	Q- Watt
MP1 (U1)	35	35	4	8
MP2 (U2)	27	27	3	4.5
MP3 (U3)	15	15	4	2.75
IC4 (U4)	12.5	12.5	3	1
IC5 (U5)	19.65	6.5	3.43	1.5
IC6 (U6)	15	20	3.5	2
MF1 (U7)	12	20	3	2
MF2 (U8)	20	20	3	1
MF3 (U9)	20	20	3	0.5

Distribution of nine non identical heat sources is done with 7 row and 5 columns as shown in Figure 1. The positions of low-powered heat sources U3, U4, and U7 (55-24-23) on SMPS PCB board are set. 32 spots are offered for six heat sources in 65, 24, 58,240 combinations.

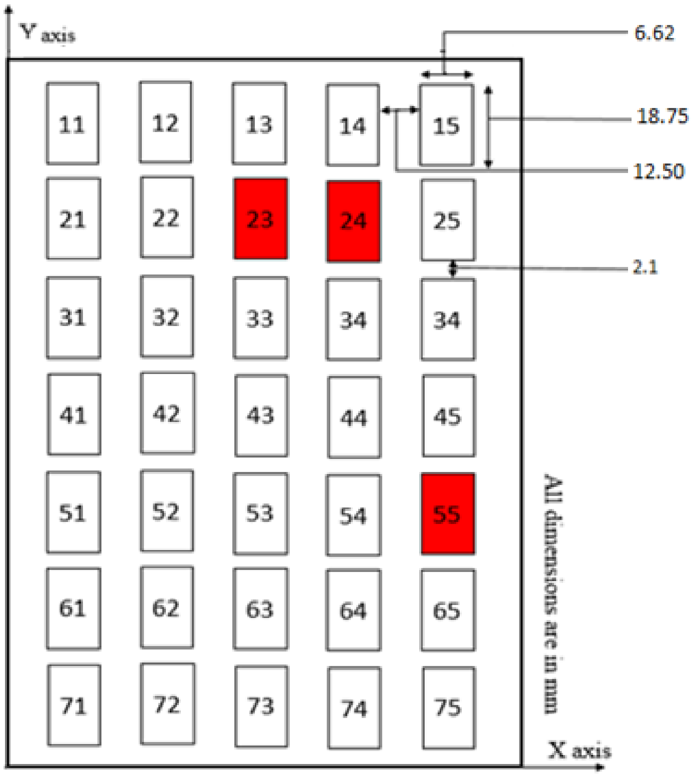

Fig. 1. PCB dimensions showing 35 locations for nine heat sources

2. Non-dimensional Geometric Distance Parameter (λ)

The various arrangements and their corresponding λ values are determined through the utilization of a MATLAB code shown in section 4.4. This non-dimensional geometric distance parameter is dependent on both size and placement factors. The λ values are computed using the equation specified.

$$\lambda = \frac{(\sum_{i=1}^{9} d_i^2)}{l^2+Y_C^2} \quad (1)$$

where the subscript i denotes the heat source number. In Eq. (1), $\sum d_i^2$ is calculated as $\sum(X_i - X_c)^2 + \sum(Y_i - Y_c)^2$, where (X_i, Y_i) denotes the centroids of ith heat sources measured from x axis and y axis of the substrate respectively.

A correlation is proposed where non-dimensional temperature (θ) is a function of lambda (λ). The non-dimensional temperature is

$$\theta = (T_{\max} - T_{\infty})/\Delta T_{\mathrm{ref}} \tag{2}$$

Here, $\Delta T_{\mathrm{ref}} = q\, l_c / K_s$.

Therefore, it is quite relevant that with increase in heat flux, the temperature of the IC chip increases and also there is thermal interaction between the IC chips when they are closely positioned. Therefore, λ is a strong function of heat flux values.

3. Numerical Setup

Natural convection is analysed using ANSYS Icepak. Figure 2 shows the test section (Cabinet), PCB (FR-4), and nine non-identical rectangular heat sources (Aluminium) employed in this investigation. Table 1 heat flux is used to simulate 47 combinations out of 65,24,58,240. Table 2 shows dimensionless parameter (λ) that has two extreme values and evenly spaced in-between values. Simulating low-powered fixed-position heat sources. The steady-state numerical simulations are performed using commercial software Ansys Fluent V16.0. The present analysis is carried using natural and convection heat transfer mode with assignment of 5HTC at the wall of solid IC chips. The adiabatic condition is created at wall domain by assigning ambient temperature of 25 during initialization. The assignment of heat source is given in terms of Watt in input to the volume of IC chip.

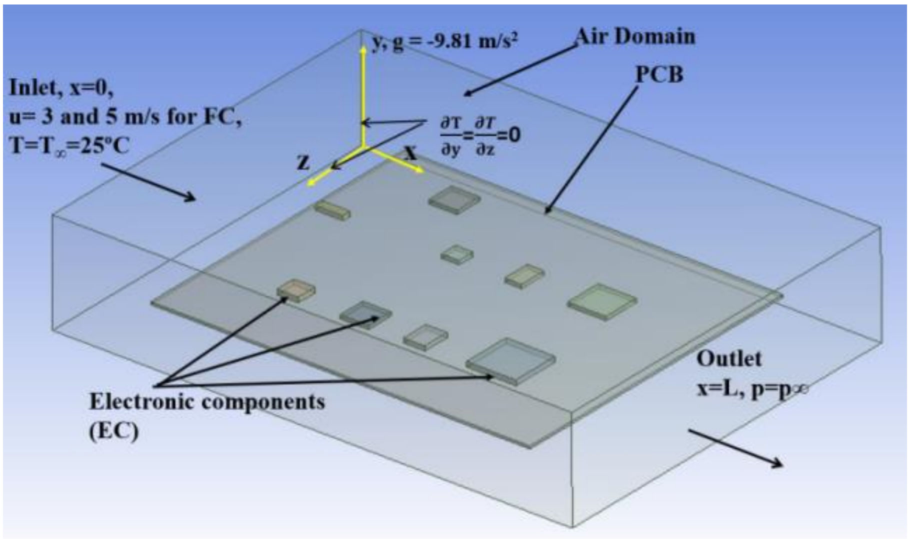

Fig. 2. Computational model

The temperature of the air entering the domain is known which is provided at the inlet but the temperature of the air exiting is not known and there is no backflow entering at the outlet port due to which the thermal boundary condition at the outlet is not provided. The temperature of the fluid exiting the outlet is based on the internal (upwind) temperature. The temperature of a fluid re-entering the domain is based on the specified temperature provided at the inlet.

4. Boundaries and Governing Equations

The boundaries and governing equations are reported from researcher Kurhade *et al.,* [15].

5. Optimal Configuration ANN-GA Approach

5.1 Artificial Neural Network (ANN)

In the current investigation, the ANN is fed and trained using numerical data. The network is trained for 65, 24, 58,240 configurations with a non-dimensional geometric distance parameter (λ) as inputs and a non-dimensional theta correlation as outputs. The weights and biases are updated with the use of the Levenberg-Marquardt algorithm, and the transfer function is a tan-sigmoid. MATLAB 2015a's neural network toolbox is used for the training process. 75% of the data trains the neural network, while 25% tests it. Figure 3 confirms a good agreement of both the data with an error band of 10%, and thus confirms the accuracy of the network.

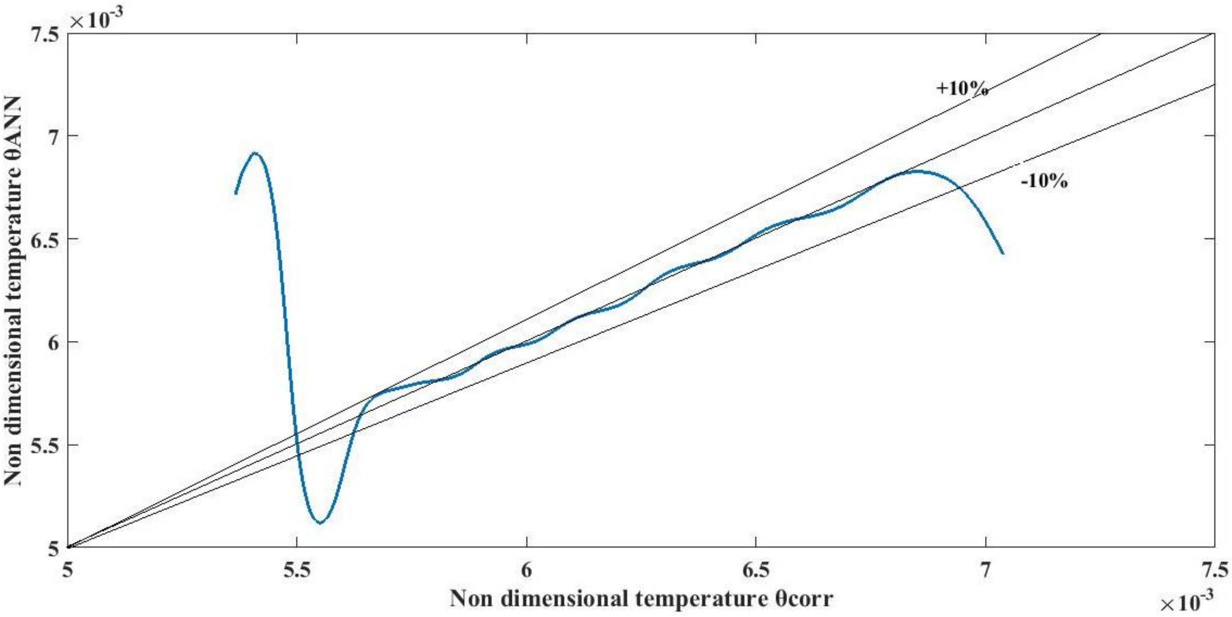

Fig. 3. Plot of Θ Correlation to Θ ANN

Neuron independence study is done using 2–20 hidden layer neurons to discover the appropriate number. After that, the MRE, MSE, and R^2 to figure out which network is best.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(T_{corr} - T_{ANN})^2 \tag{3}$$

$$MRE = \frac{1}{n}\sum_{i=1}^{n}\frac{|T_{corr}-T_{ANN}|}{T_{corr}} \tag{4}$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(T_{corr}- T_{ANN})^2}{\sum_{i=1}^{n}(T_{corr})^2}\right] \tag{5}$$

Table 2 shows that when comparing networks of different sizes, 10 neurons have the highest MRE, MSE, and R2. The GA is decided to be powered by this ideal network. In Figure 3, we have a Parity diagram of the ANN-obtained non-dimensional temperature theta (ANN) vs the theta correlation (eqn).

Table 2
Neuron autonomy research

Neurons	MSE	MRE	R^2
2	7.86×10^{-8}	0.0372	0.780
5	2.17×10^{-9}	0.0055	0.986
7	2.87×10^{-9}	0.0047	0.982
10	1.67×10^{-9}	0.0029	0.988
15	4.05×10^{-9}	0.0057	0.975
20	5.17×10^{-9}	0.0066	0.968

5.2 Genetic Algorithm (GA)

The genetic algorithm is influenced by biology that uses the concepts of natural selection and heredity. In this case, we take into account a pool of solutions that was produced at random values are computed by plugging in the appropriate values for the variables in the fitness function, which is assessed here using the ANN results. To generate a new population, crucial processes include reproduction, genetic crossover, and mutation. Minimizing the non-dimensional temperature is the target of the GA optimization. In this scenario, the ANN has been trained to produce a non-dimensional temperature value. When the genetic algorithm is run until convergence, it reveals the population's fitness value. The configuration with the lowest non-dimensional temperature. A sample size of 50 individuals was used for this study, and a crossover frequency of 0.8 was assumed. The objective of the GA is to minimize the non-dimensional maximum temperature excess, θ. Thus, the objective function is expressed as,

$$\text{minimize } \theta \tag{6}$$

Subjected to $0.232 \leq \lambda \leq 1.548$ and $0.066 \text{ W/cm}^2 \leq q \leq 4.38 \text{ W/cm}^2$.

In this scenario, the θ value is supplied by the trained ANN. The genetic algorithm (GA) runs until the convergence criteria are met, which involves assessing the fitness value of the population, specifically targeting the lowest non-dimensional maximum temperature excess across all configurations. In this particular instance, the population size is set at 50, with a crossover fraction of 0.8.

5.3 Integration of ANN and GA

The hybrid optimization strategy offers a more robust and efficient approach to predicting the arrangement of IC chips on a substrate board compared to conventional methods. By synergistically combining the strengths of ANN and GA, it can overcome the limitations of deterministic algorithms and manual design processes, leading to more accurate and optimized chip layouts. The flow chart shown in Figure 4 illustrates the methodology for determining the global optimal position of the seven non-identical rectangular IC chips arranged at different positions on the SMPS board [10].

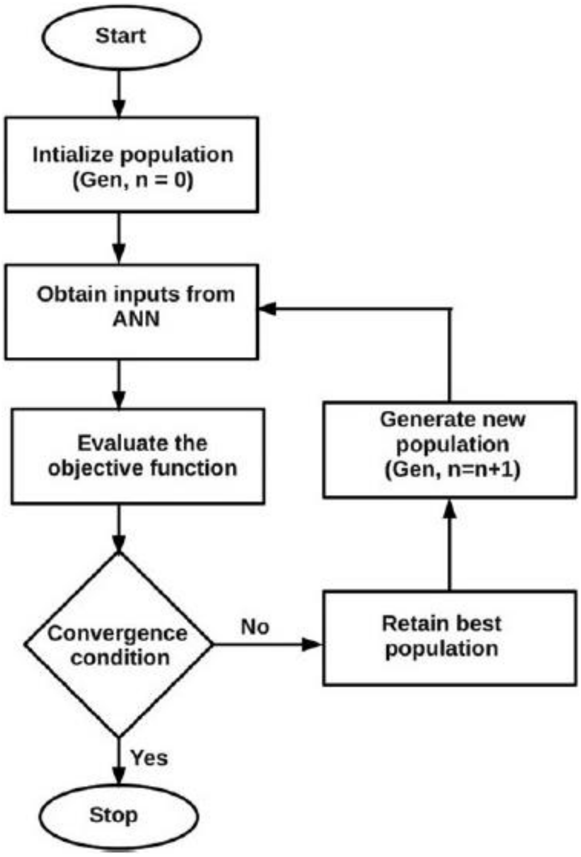

Fig. 4. GA flowchart for best heat source settings [10]

Figure 4 shows the GA flowchart for best heat source settings. Next, we simulate this best-case setup in ANSYS Icepak to find out which of the nine heat sources produces the highest temperature (Tmax), and we get a result of 78.44 °C. This figure matches GA data with an error of 2.24%. shown in Figure 5.

In order to establish the globally best configuration of heat sources, we integrate ANN with GA, this helps GA optimize faster by reducing simulations. Numerical simulations are run in GA until convergence is obtained, after which the optimum ANN network is imported. After 41 generations, GA reaches the best possible outcome.

The GA yields a fitness value of 0.00512, as depicted in Figure 5, with the corresponding λ value being 1.58830. Additionally, the impact of generations on the fitness value of the optimal configuration is examined, revealing that augmenting the number of generations has minimal influence on the maximum temperature of the configuration.

Figure 6 demonstrates that when air moves beneath the IC chips, there is minimal thermal influence between them. Conversely, in Figure 7, when air flows over the upper surface of the IC chips, a notable interaction among the chips occurs, facilitating efficient heat dissipation. Consequently, this accelerates the cooling process of the IC chips and substantially reduces their temperature.

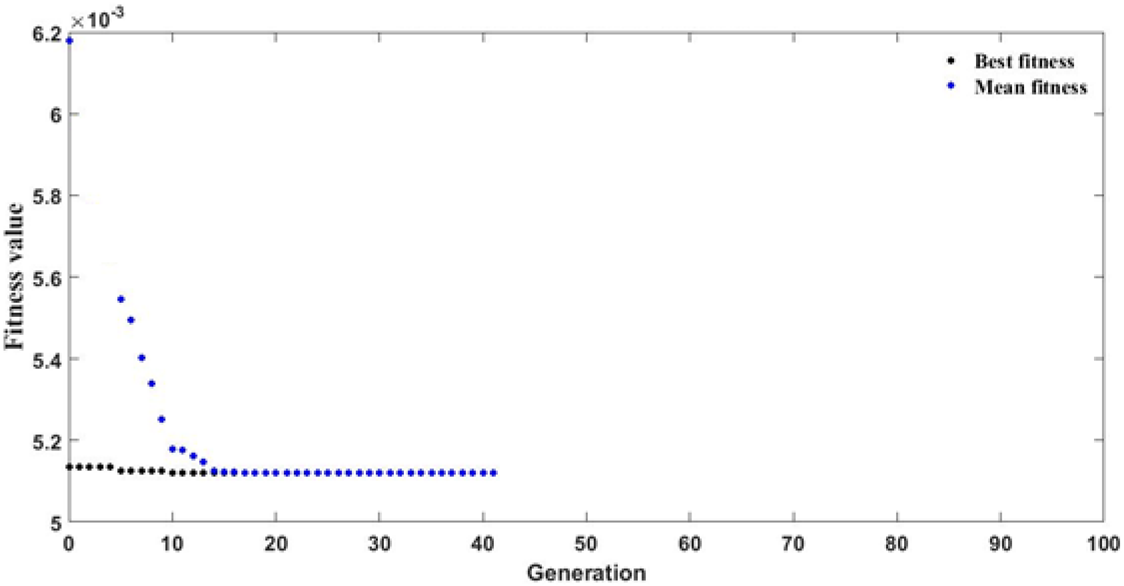

Fig. 5. The best configuration's fitness value (non-dimensional temperature θ) for different generations

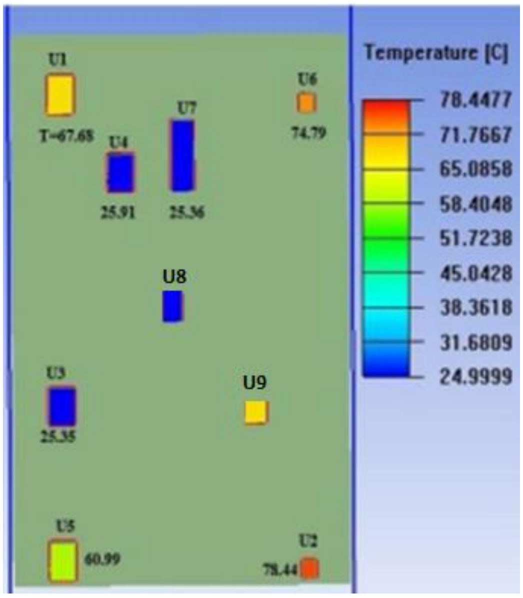

Fig. 6. Optimal configuration generated by GA, λ = 1.58830

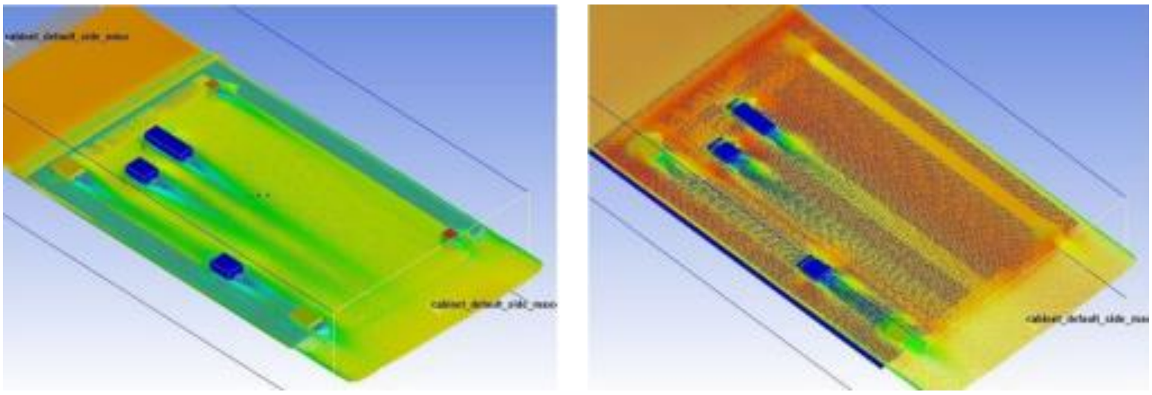

Fig. 7. Velocity profile for the optimal configuration obtained using GA

5.4 Actual Matlab Program

```
clc;
clear;
a=35; %Slot width
b=35; %Slot length
c=7; %No. of rows
d=5; %No. of slots in each row
Wkg_area=160; %Working area size
F=[5;5;5;5;5;5]; %Spacing between two slots in a row
E=[5;5;5;5;5]; %Spacing between two slots in a column
G=[35 35;27 27;15 15;12.5 12.5;19.65 6.5;15 20;12   20;20 20;20 20];
e=size(G,1);
Sum_A=0;
for f=1:1:e
Sum_A=Sum_A+G(f,1)*G(f,2);
end
load T.txt;
load C.txt;
comb_count=size(C,1);
t=0;
k=24;
for m=1:comb_count
sum_Ax=0;
sum_Ay=0;
t=t+1;
  for i=1:9
    A=C(m,i);
      for j=1:24
          if A==T(j,1)
              x(i)= T(j,2)+G(i,1)/2;
              y(i)= T(j,3)+G(i,2)/2;
sum_Ax = sum_Ax + x(i)*G(i,1)*G(i,2);
sum_Ay = sum_Ay + y(i)*G(i,1)*G(i,2);
          end
      end
  end
  xc = (sum_Ax)/(Sum_A);
yc = (sum_Ay)/(Sum_A);
di_square=0;
        for i=1:e
di_square = di_square + (x(i)-xc)^2 + (y(i)-yc)^2;
        end
Lamda(t,1)=(di_square)/(Wkg_area^2 + yc^2);
end
```

6. Conclusions

The Nine rectangular heat sources of varying sizes are put on a PCB, and their ideal arrangement is determined numerically by simulating their behavior under natural convection. It is found that the non-dimensional geometric parameter distance (λ) is a function of the location of the heat source, whereas the non-dimensional geometric parameter temperature theta is a strong function of heat flow and maximum temperature excess. The maximum temperature surplus is minimised at higher, and a correlation is given to show that this is the case as increases. The best possible simulation results are used to power a genetic algorithm (GA) that finds the ideal configuration in which the heat sources' temperatures are far below their maximum operating condition, as specified in data sheets. The maximum temperature variation between the lowest and highest extreme configurations ranges between 4 - 8%. There is good agreement of both the data with an error band of 10%, and thus confirms the accuracy of the network.

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