Increasing population diversity in genetic algorithm for solving Two-Dimensional nesting problems

Mehmet HACIBEYOGLU, Mohammed Hussein Ibrahim

Abstract— **The main objective of two-dimensional nesting problem is finding the optimum order and placement of regular and irregular two-dimensional objects without overlapping on the sheet which has a limited width and unlimited length. This problem is an NP-hard problem so the complexity of the nesting process increases directly proportional to the increase in the number of objects. For this reason, metaheuristic algorithms are often used for solving this problem. The main criteria in solving this problem are reducing the rate of waste sheet and increasing the speed of nesting objects. In this paper we have proposed new methods in crossover and mutation processes for increasing the diversity of the population in genetic algorithm, which directly affects the performance of the genetic algorithm. The proposed method implemented and tested on 6 different nesting datasets.**

Index Terms— **genetic algorithm, irregular shape, Nesting, optimization problem, regular shape**

I. INTRODUCTION

In today's competitive manufacturing market, manufacturers are working hard for increasing the efficiency of the production. This process is also known as to reduce the raw material costs and shorten the labour time. During the industrial production process a huge amount of raw waste material are emerging during the cutting operations. Nesting is used for reducing this waste raw material in numerous industries, such as furniture, garment, footwear and sheet metal [1], [2]. Nesting is an old problem of finding the optimum layout of cutting parts out of raw material with minimum wastage. In some industries, many manufacturers still continue to use manual methods. Operators determine the placement or layout of the cutting parts with their experiences. However, this is not an efficient way because when the number of cutting parts is increased the time of nesting process will be increased exponentially and the error rate of human intelligence will increase [3].

Nesting is an NP hard optimization problem and finding the best solution in a reasonable time period is very difficult. For solving this problem, building and evaluating layouts are the most basic operations. This includes avoiding overlap between two pieces and placing the pieces inside the sheet with the minimum height. In order to achieve a good layout, a good strategy and algorithm is needed. The used algorithms are high level search algorithms that need to perform a global search over the solution space to ensure the optimal result. Therefore many studies have been conducted for solving this problem with different shape parts on different shaped sheets, which include new algorithms and methods.

To increase the performance and speed of the algorithm, it is possible to use hybrid algorithms for solving the problem of the placement. (Hifi, M. and M'Hallah, R. 2003) proposed two algorithms for solving the two-dimensional nesting problems. The first algorithm designed specifically for non-regular shapes and also works well with regular shapes, the second is a hybrid algorithm which builds a chromosome which affects the development of genetic algorithm (GA). (Lee, W. C., Ma, H. and Cheng, B. W. 2008) proposed a new hybrid approach, to represent and prevent overlap in placement shapes used Two-stage packing approach. The representation of shapes in the form of digits one or zero where one represent filled space and zero empty space. And a genetic algorithm is used to determine the shapes orderings.

Nesting problem is a discrete problem, but many researcher have solved this problem with continuous based metaheuristic algorithms. (Jiang, J. Q., Liang, Y. C., Shi, X. H., and Lee, H. P. 2004) proposed a hybrid algorithm based on particle swarm optimization (PSO) and simulated annealing (SA) for finding the optimal placement of objects and compared the results with the standard PSO. As a result, they found that the hybrid algorithm gives better performance than standard PSO algorithm when the number of the objects are increased.

(Terashima-Marín, H., Farías Zárate, C. J., Ross, P., and Valenzuela-Rendón, M. 2006) explores a new method of the usage of evolutionary approaches to generate hyper-heuristics for solving nesting problem. (M. Matayoshi; 2011; M. Matayoshi; 2010) proposed new methods in the structure and arrangement of chromosomes in genetic algorithm used to nest irregular shaped objects containing four or more right angles.

In this paper, we propose a novel usage of the genetic algorithm where the parts are nested on a sheet with binary coding. We use a logic operation for overlap detection of the parts and we test proposed method with several datasets.

II. DESCRIPTION OF 2-DIMENSIONAL NESTING PROBLEM

Nesting is a classic NP-hard optimization problem in computer science and optimization literature. The goal of the problem is to find the optimum arrangement of the parts for minimizing the waste or maximizing the utilization of the sheet. There are several types of nesting problem. These are 1-dimensional, 2-dimensional and n-dimensional problems [1], [4]. The most studied nesting problem is 2-dimensional cutting and packing problem. For solving this problem the set of parts must be placed with the correct sequence and angle without overlapping. In figure 1, an example of 2-dimensional nesting problem is given:

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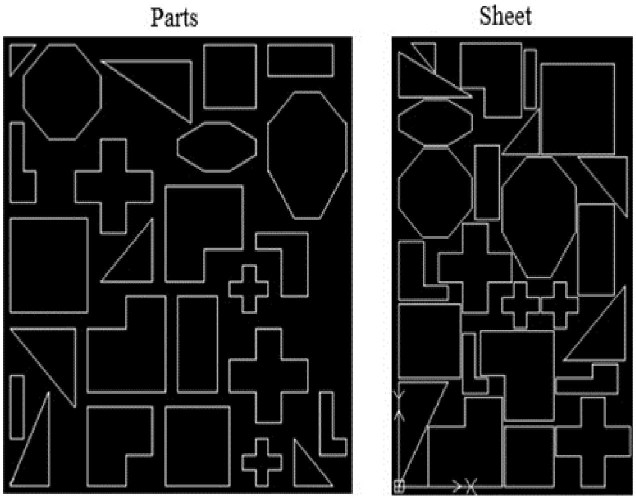

Fig. 1, an example of 2-dimensional nesting problem

III. Representation of the Regular/Irregular Objects and Sheet with Pixel/Raster Method

The Pixel/Raster method represents the part with binary system using a number matrix includes digits 1 and 0. In this matrix an existing part is presented by 1 and an empty space is presented by 0. An example representation of pixel/raster method is given in Figure 2. Moreover, at the beginning of the nesting process all sheet matrix equals to 0.

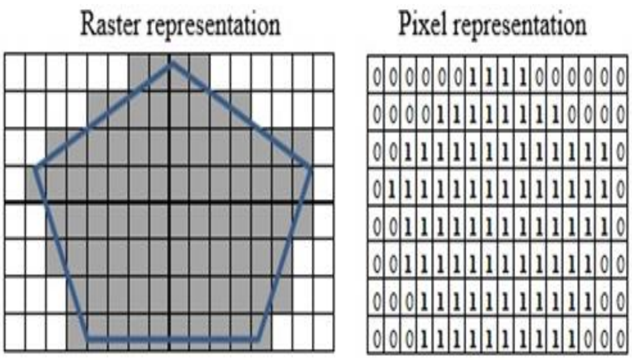

Fig. 2, an example of Pixel/Raster representation

IV. Nesting Parts without Overlapping

After the representation of the parts, the parts will be placed on the sheet without overlapping. Oliveira and Ferreira [13] proposed a method with pixel/raster representation for overlapping detection. In this method if a pixel gets a value greater than 1, then it means that there is overlapping in the given pixel. An example of this method is given in Figure 3.

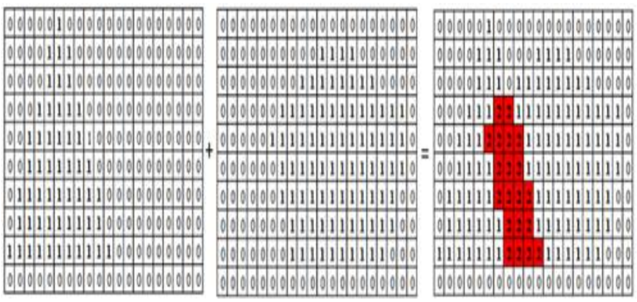

Fig. 3, an example of overlap detection with pixel/raster representation

In this study, we propose a new method for overlapping detection with bitwise AND operator. In this method, we process the pixel raster matrix line by line. The AND operation is performed between the next line in the matrix of the part to be nested and the next line of the matrix of the sheet. If the results of the AND operations are 0 for all lines, the coordinates of the part to be nested is suitable; else the coordinate of the part to be nested must be moved up one line until it reached to the top line. If the method reached to the top line then the coordinate of the nested part must be moved to the bottom line of the right column. An example of the AND operation for the first and seventh columns of the sheet and part to be nested are given in Figure 4.

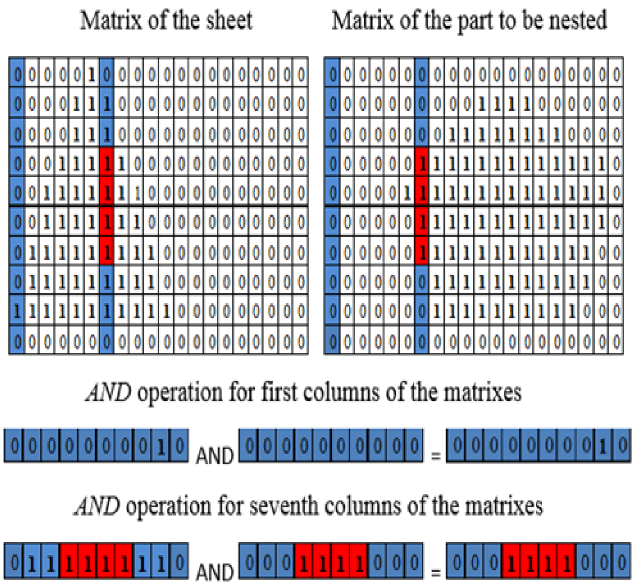

Fig. 4, an example of the overlap detection with the proposed method

V. A Novel Use of Genetic Algorithm for Nesting Problem

The quality of the layout, which is constructed using heuristic algorithms, strongly depends on the sequence and the orientation of the parts to be nested. Every permutations of the items in every feasible position and orientation give the full state of solutions. Since the number of combinations is too large to be explored exhaustively in reasonable amount of time, heuristic and meta-heuristic algorithms are used as a more efficient search strategy [12]. GA is a method for solving optimization problems like nesting [10]. In this paper, we proposed a novel use of the GA for nesting. There are several genetic operations in GA for finding the optimal solution. These are chromosome coding, initial population, evaluation of fitness function and new generation selection, crossover and mutation processes. In this paper these processes are made in a new approach as explained below.

A. *Chromosome Representation*

For an efficient nesting, the parts must be in the correct order and orientation. So this is a combinatorial optimization problem. In this problem, we represented the chromosomes as an array of numbers consisting of two parts. The first part represents the part index and the second part represents the angle of the part. An example of possibilities of genes with four parts and four angle orientations which will create the chromosome are given in Figure 5.

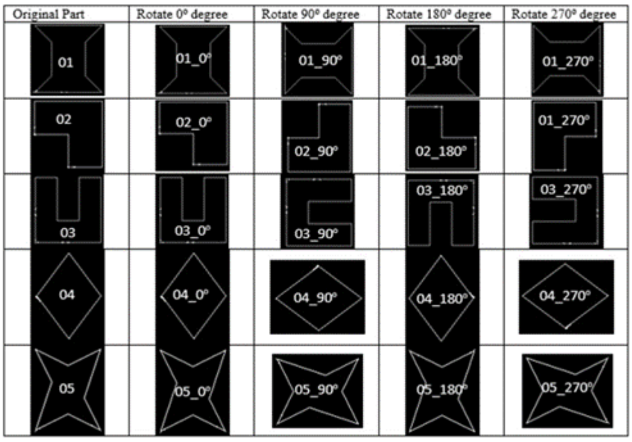

Fig. 5, an example of the genes

According to Figure 5, examples of two chromosomes consisting of five genes can be generated as follows: Shown in Figure 6.

Chromosome 1:	4_90	5_180	1_0	2_270	3_90
Chromosome 2:	04_0	1_90	2_180	3_90	5_270

Fig. 6, Two chromosomes each one consisting of five genes

B. Fitness value and Selection Process

GA needs a fitness value which defines the importance of the chromosome in the population. The parts are nested to the sheet starting from the bottom left corner. Because the height of the sheet is fixed, the fitness value of the GA is the width where the objects are arranged. The selection process is very important in the structure of the algorithm, it is used to choose the strong parents. There are several methods for the selection process, Roulette Wheel Selection, Stochastic Universal Sampling (SUS), Linear Rank Selection (LRS) and Exponential Rank Selection (ERS) [13].In this study, we have implemented tournament selection method with five candidates for selection process. In this method, five candidates are determined randomly from the population. The chromosome with the lowest fitness value which is the champion of the tournament is transferred to the new generation. The fitness value F is calculated according to equation 1 is shown below.

$$F = \frac{SA}{\sum_{i=1}^{n} IA_i} \qquad (1)$$

Where, n represents the number of objects, IAi represents the area of ith object and SA represents the sheet area.

C. Crossover and Mutation Operations

Crossover and Mutation operators are performed to increase the diversity of the population. There is more than one type of crossover process in genetic algorithm such as Single-point Crossover, N-point crossover, Uniform Crossover and Flat Crossover [14], [15]. In this paper, we used two point crossover operation to change the order of the parts and mutation to change the orientation of the parts. In the crossover process, two random points are generated for parent chromosomes and the parts between these numbers are changed oppositely. For the mutation process, a new random angle between 0 and 360 is selected for a particular part and changed in the chromosome. An example of the crossover and mutation processes is given in Figure 7.

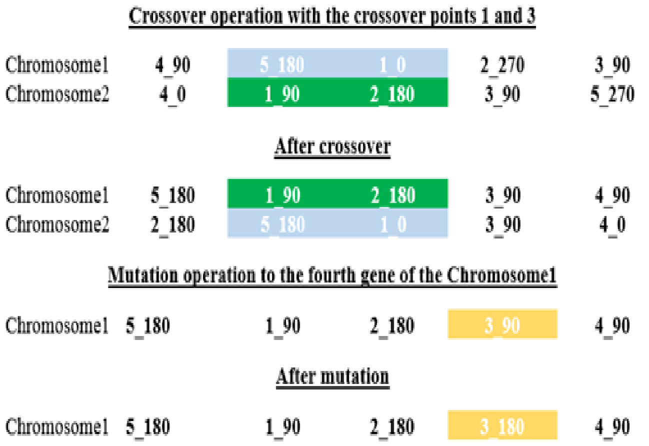

Fig. 7, an example of crossover and mutation processes

D. Generating a new population

Initial population is obtained after crossover and mutation processes. For the next iteration, the new fitness values of the chromosomes are calculated for choosing the best solution Algorithm steps are repeated until the iteration limit is obtained.

VI. Experimental Results

This section reports on the experiments of the proposed algorithm. The proposed algorithm has been implemented using C# compiled by Visual Studio 2012. Experiments are performed using 6 different datasets. In the experiments, we used a target machine with an Intel Core i7-3840QM 2.8 GHz processor and 16 GB memory, running on Microsoft 8 operation system. The parameters of proposed GA is given in Table I.

Table I. The parameters of proposed GA

Parameter name	**Value**
Population Size	500
Number of iterations	5
Crossover rate	0.85
Mutation rate	0.05

The results are evaluated according to the efficiencies and computational times. The properties of the used datasets, the height and width of the nesting sheet, the rate of productivity and the measured CPU-Times are given in Table II.

Table II. Efficiencies and computational times of the experiments

No	*DN*	*NP*	*NS (h*w)*	*P*	*T(s)*
1	Blaz	28	15 x 29,7	72,73	109,11
2	Jakobs1	25	40 x 13,2	73,74	43,67
3	Jakobs2	25	70 x 28,2	68,32	819,37
4	Fu	12	38 x 36,2	78,72	213,62
5	Han	23	58 x 45	75,44	798,35
6	Marques	24	104x 84,5	81,86	2916,25

Where, DN is the Dataset Name, NP is Number of parts, NS (h*w) is Nested sheet (height * width), P is the rate of the productivity and T is the measured CPU-Time (seconds).

The layouts of the six datasets are given respectively in Figure 8, 9, 10, 11, 12 and 13.

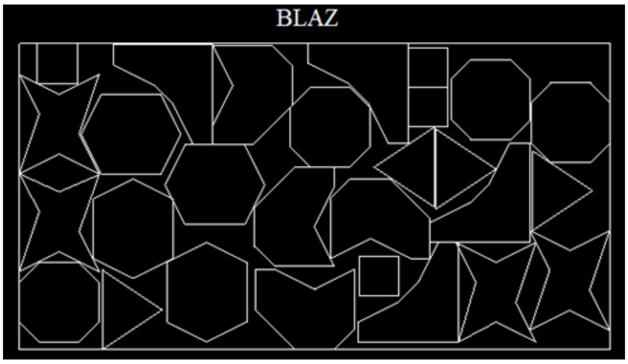

Fig. 8, the layout of the dataset BLAZ

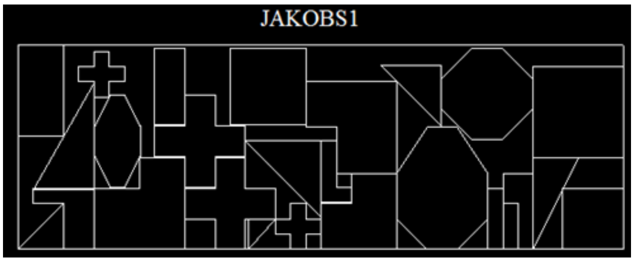

Fig. 9, the layout of the dataset JAKOBS1

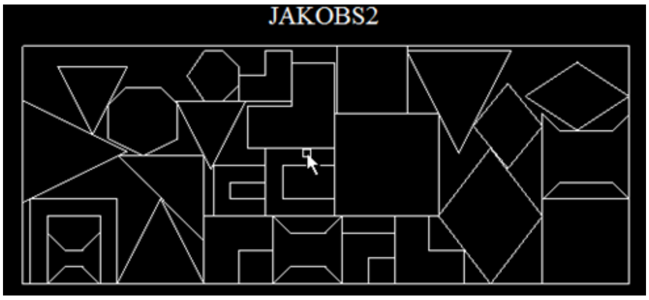

Fig. 10, the layout of the dataset JAKOBS2

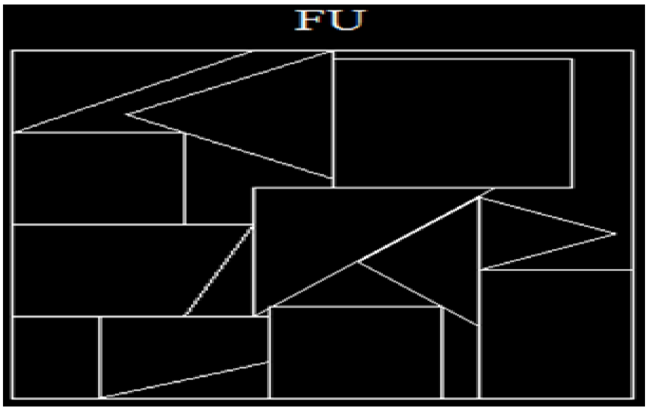

Fig. 11, the layout of the dataset FU

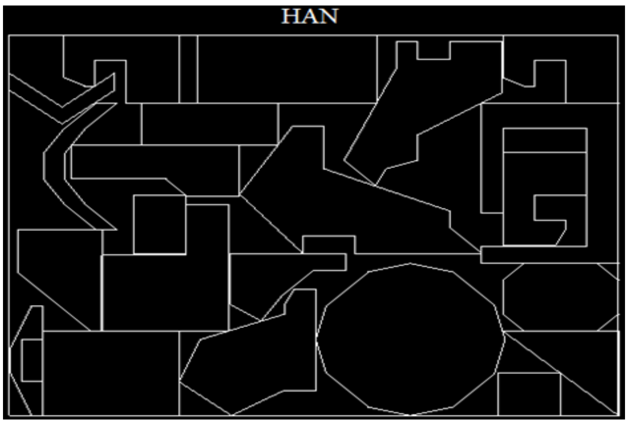

Fig. 12, the layout of the dataset HAN

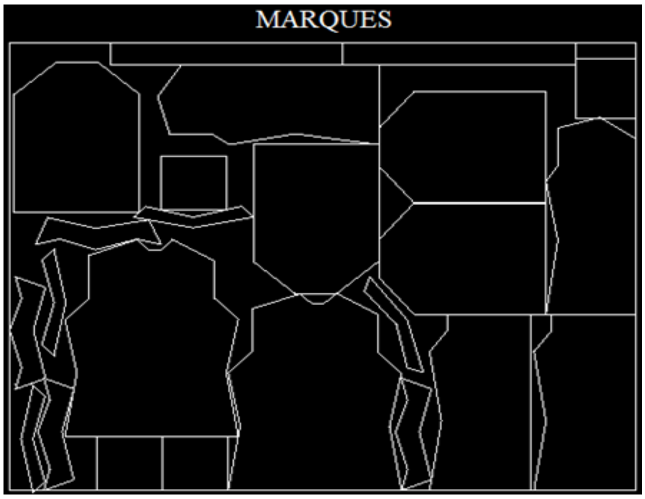

Fig. 13, the layout of the dataset MARQUES

VII. Conclusion

2-diomensional nesting problems are optimization problems that are interested in finding a good order of parts on the sheet. This type of problem is performed in many areas of industry. There are many algorithms to solve the 2-diomensional nesting problem. In this paper, a novel use of the genetic algorithm with increasing the population diversity is presented for solving 2-diomensional nesting problem. One of the main objective of this study is to increase the efficiency and accuracy of the algorithm. On the other hand, the parts to be nested are represented with binary matrix and overlapping detection is performed using bitwise AND operation. The chromosome representation, crossover and mutation operations are made by a new way. For future work, the efficiency of the algorithm may be increased using with other metaheuristic methods.

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