Implementating the Genetic Algorithm with VLSI Approach for Optimization of Sheet Metal Nesting

K.Ramesh[1*], N.Baskar [2]

[*1] Department of Mechanical Engineering, M.I.E.T Engineering College,

Tiruchirappalli, Tamil Nadu - 620 007, India.

[2]Department of Mechanical Engineeering, M.A.M College of Engineering,

Tiruchirappalli, Tamil Nadu-621 105, India.

Abstract

As Engineering becomes more advanced and the business in the industrial world becomes more competitive, hence optimization technique becomes an essential part of an any industry or organization. The objective of this paper is to minimize the material wastage by the optimum layout of two-dimensional work piece within constraints imposed by stock size and material. This approach deals with how it can be effectively utilized in the sheet metal industry to have the best arrangement of irregular shaped parts in the sheet. This can be possible by using genetic algorithm (GA) approach which provides a best sequence of parts with their orientation and also deals with how the parts can be effectively utilized in sheet metal. This analysis mainly depends on the cutting process, size and shape of the sheet for different combination of parts and subsequent operations required on the part. This heuristic based genetic algorithm generates optimum layout considering factors such as minimum material wastage with their orientation by eliminating human efforts.

Keywords: Genetic Algorithm, initial population, cross over, mutation, strip

1. Introduction

The nesting of two-dimensional shapes for press tool design is general optimization problem. In mass production industries, small inefficiencies will lead to very large material wastage. This is also known as two-dimensional cutting stock problem. This problem is commonly encountered in industries such as lock, Sheet metal, aerospace, shipbuilding, clothes and shoe manufacturing. The problem was solved by using mathematical technique in the earlier stage.

The irregular parts are considered as orthogonal line features. Arrangements of parts on a sheet depends on the sequence which the parts with their orientation. In order to generate an optimum arranged pattern, it is essential parts in proper sequence and their orientations.

The complete procedure considers all possible combinations of part sequence and their orientation to give out the optimum nested pattern. But it takes considerably longer time to achieve the optimum solution. Such a computational complexity can be overcome with genetic algorithm.

Once the sequence and orientations of parts are selected randomly, parts are to be arranged on the sheet in acceptable positions. The acceptable position of the part is the one where the part neither overlaps with other neither nested parts nor crosses the boundary of the strip. It is necessary to find out the position of the part, with other the over lapping parts that are nested already. Hence this technique is employed in which the center of all parts which lies in the same line and quickly identify the position the part with respect to the strip.

Antonio Albano and Giusseppe Sapuppo developed an automatic approach, which transforms the allocation problem into a search process through a “space” of candidate solution. Since this space is very large, heuristic algorithm will be employed for shortening the search. This search indicates the optimal arrangement of irregular parts into a rectangular resource. The problem had been to a search of an optimal path in a graph, and an algorithm had been implanted which provides an approximate solution with less process time.

A.Y.Nee, V.C.Venkatesh developed a heuristic algorithm for the layout of metal stamping blanks with computer user friendly dialogue. The algorithm creates an optimum layout considering factors such as minimum material wastage, bridge width and grain orientation. These above factors provide information about stock purchase with press center. This solution can be generated with favorable trial and error method. The researchers was discussed various factors which are normally encountered in the stamping operations such as material saving, bridge width, stock width, direction of rolling, press capacity, blanking pressure and die design consideration etc.

Nee et al developed the two algorithms. The first algorithm rotates the blank with rotates angles and places the blanks side by side, giving due consideration for the bridge width requirement. The solution with the highest utilization ratio is then adopted. In this solution a two-degree incremental is used to determine the utilization ratio at various angles of tilt.

The second algorithm indicates a pair wise clustering. In this method a polygon id first reoriented such that one of its sides coincides with the X-axis. A second polygon at 180^0 orientation to the first is used to match the various sides on the first polygon. If the two polygon overlaps, a preset incremental shift is performed until such over lapping is completely cleared. The composite figures are again re-oriented to obtain the smallest enclosing rectangular module. This process is repeated on the remaining sides of the polygon until every side has been tested. Six smallest sets of the rectangular enclosures are retained. The modules selected are further packed to arrive at final layout.

H.S.Ismail and K.K.B Hon developed two approaches, which is, based on automatic pair wise clustering of two dimensional shapes for press tool design. The first is based on a simple edge detection algorithm and the second is an experimental procedure based on the concept of genetic algorithm. DXF file, which contains information about line and geometrical features of the two-dimensional shapes, converted into input data and the bridge width is added depending upon our requirement. Common to both approaches is the procedure by which the data describing the two-dimensional shapes. The preliminary data transformation procedures required converting the shape into a format acceptable to the main processing routines.

T.J.Nye developed an algorithm for orienting a single arbitrary blank on a strip so that raw material is optimally utilized. The blank is represented as a simple polygon. The blanks with curved edges are approximated as polygons, with the approximation improving as the number of vertices on the polygon increase. It is assumed that the width of the strip is determined during the layout optimization rather than being pre-specified before the layout works starts.

2. Genetic Algorithm

Many optimization problems from the Industrial Engineering World, in particular the manufacturing systems are very complex in nature and quite hard to solve by conventional optimization techniques. Simulating the natural evolutionary process of human being results in stochastic optimization techniques which is called evolutionary algorithms, which can often out-perform the conventional optimization methods when applied to difficult real world problems.

GA has received considerable attention regarding their potential as an optimization technique for complex problems and has been successfully applied in the area of industrial engineering. The well known application include scheduling, sequencing, reliability design, GT etc., the idea of evolutionary computing was introduced in above said field from the year of 1960s by I.Rechenberg in his work namely ‘evolution strategies’. Other researchers further developed his idea.

Genetic Algorithm is search algorithm based on the mechanisms of natural selection and natural genetics. John Holland, his colleagues, and the students developed this technique; basically, these algorithms are difficult from normal optimization techniques and search procedures in four ways:

1. GA’s work with a coding and search of parameter set not parameter themselves.
2. GA’s search from a population of points, not a single point.
3. GA’s use pay-off values (objective function) information, not derivatives.
4. GA’s use probabilistic transition rules not deterministic rules.

2.1. Coding of the Strings

In order to code the strings randomly ,each part is represented with an integer number. The genetic string represents the part sequence with their orientation. A typical genetic string for nesting of three parts is given by

2 34 1 72 3 56

In the above string the first digit represents the part number, the consecutive two digits represents the part orientation. ie the angle of rotation of the part is 360X34/99. And these data’s are assigned for consecutive parts.

2.2. Evaluation of Objective Function

The Genetic Algorithm generates an effective nested pattern by arranging the parts with their orientation on the strip. The effectiveness of the nested pattern is evolved in terms of percentage utilization of the strip . Since the nested pattern can occupy different length of strip, the percentage utilization of material is estimated as the ratio of total area of the irregular part to the total area of the strip to the length of the nested pattern.

$$O(S) = \sum_{i=1}^{n} \left[\frac{A_i}{A_s} \right] \qquad (1)$$

O(S) - No of parts to be nested

A_i- area of the irregular part

A_s- area of the sheet metal

As the effectiveness of the nested pattern depends upon the sequence of parts and their orientation. GA works the population of strings and makes use of several genetic operators such as selection or reproduction, cross over and mutation in finding out the best sequence of the parts with their orientation for maximizing the objective function.

The necessary data for the proposed nesting algorithm is provided by the geometry of the sheet metal and the parts. Each irregular part is created in the AutoCAD 2000 drawing editor and corresponding DWG files are created. The DWG files created by AutoCAD 2000 will contain the information about the geometrical features such as line and their coordinates values in a standard text form. The nesting process begins with genetic process, which involves with the coding of the strings, creation of initial population, evaluation of the objective function, cross over and mutation.

2.3. Initial Population

This is first step of the Genetic Algorithm process. It is created by generating the random numbers. The generation of random number varies from time to time.

2.4. Selection Mechanism

Selection process selects the strings from the initial population proportionate to their fitness value. Hence the chances of selecting a string are more than its fitness value is high. In general, the weaker strings will not be selected for the selection process. This ensures the policy of 'survival of Fitter'. The following relation gives the probability of selecting the i^{th} string

$$P_i = \frac{F_i}{F_{avg}} \qquad (2)$$

Where,
F_{avg} – Average value of the fitness function
Pi – Probability of selecting the i^{th} string
Fi- the fitness of the i^{th} string

Three measures of the performance of the selection process are 'bias, spread and efficiency'. Bias defines the absolute difference between the actual and expected selection probabilities of individuals. Speed is the range in the possible number of trials that may be individually achieved. The efficiency is related to overall time complexity of the algorithm.

In most practice, a proportionate selection approach is adopted as the selection procedure. It belongs to the fitness proportional selection and can select a new population with respect to the probability distribution based on the fitness value. The approach can be constructed as follows:

1. Calculate the fitness value for each chromosome.
2. Calculate total fitness value for the population.
3. Calculate selection probability for each chromosome.
4. Calculate cumulative probability for each chromosome.

Using the above selection process a new population is created.

2.5. Cross over Operation

Crossover is the operation of partial exchange of information between two strings that changes the sequence and orientation of parts to be nested. Each string in the selection process is subjected to crossover operation with the cross over probability p_c, which normally lies in the range 0.5 to 0.9. However the selection process will not produce any new chromosome but the crossover can.

An example for cross over,We can select an random number for choosing the cross over limit from the length of the chromosome.Cross over operation may produce good 'offspring'.

Chromosome Before cross over

3 86 2 **06 1 94 4 36**
1 02 2 **57 4 10 3 79**
Cross over point

Chromosome After cross over
3 86 2 **57 1 10 4 79**
1 02 2 **06 4 94 3 36**

2.6. Mutation Operation

Mutation is the secondary operation that has done in the Genetic Algorithm process. This change a bit of the string with low probability. In order to subject the string for mutation, a random number is generated from 1 to the length of the chromosome. The number of strings to be mutated depends upon the mutation probability p_m and it is given by the following formula:

Length of the chromosome X population size X p_m = Number of strings to be mutated

Generally the mutation probability lies between 0 to 1 to be more precise it assumes the value in the range 0.001 to 0.5. Since we are the real coded GA, the minimum amount of bits to be mutated will be two and its sum.

An example for mutation process:Here the selected bit of the chromosome can be replaced by another by the random walk.

Chromosome Before mutation
3 86 2 57 1 **10** 4 79
1 02 2 **06** 4 94 3 36
Chromosome After mutation
3 86 2 57 1 **06** 4 79
1 02 2 **10** 4 94 3 36

2.6.1. Types Of Mutation:

1. Using single chromosome:

For this process we have to generate two integer random numbers from 01 to the length of the chromosome.

Chromosome Before mutation:
Mutation points
3 **86** 2 57 1 **06** 4 79
Chromosome After mutation:
3 **06** 2 57 1 **86** 4 79

2. Using two chromosomes:

Chromosome before mutation:
3 86 2 57 1 **10** 4 79
1 02 2 **06** 4 94 3 36
Chromosome after mutation:
3 86 2 57 1 **06** 4 79
1 02 2 **10** 4 94 3 36

Advantage of the first method over the second is the probability of two bits to be mutated is 1. But in the second case there is chance that the mutation points lies on bits, which have same numerical value.

3.Proposed Methodology:

The lock industry is currently manufacturing various types of keys and locks. The part details and their respective drawings regarding the locks has been collected from the industry. The industry uses sheet metal for fabricating the keys and locks. The part drawings, which are used for optimization problem, denote the various types of levers, which are used for manufacturing the locks.

The part drawings which are used for optimization problem, have been selected from the AutoCAD 2000 drawing editor. The AutoCAD 2000 provides the necessary data such as area of the part, co-ordinate values with respect to the center of the part regarding the nesting process. In order to avoid the over lapping of the parts during the genetic process, selected parts are approximated to a rectangle and their boundaries are fixed. The center points for all the irregular shapes have been found. The center point can be used as a base point to obtain different orientations. The various orientations of the parts can be achieved by rotating the parts in either clock-wise or anti-clockwise direction with respect to the center point.

In order to obtain good utilization factor, the orientational accuracy has to be fine-tuned. This can made possible by having very high orientational value. The various possible orientation of the each irregular part can be obtained by generating the random number from 1 to 9 or 1 to 99 or 1 to 999 etc. The following relation can be used to achieve various orientations:

$$S = 360 \text{ X } n/C$$

Where,
S – Orientation
n- Generated random number
C – Orientational accuracy (9, 99, 999, 9999…)

3.1.Creation of the drawing:

In this work the chromosome will be in the form:

1 46 2 13 3 76

Here 3,2,1 denotes the part number and the remaining 46, 13, 76 represents the orientation.
From the above chromosome the part number 1 has to be placed at 46^{th} orientation .

S = 360 X 46/99

S = 167.28^0

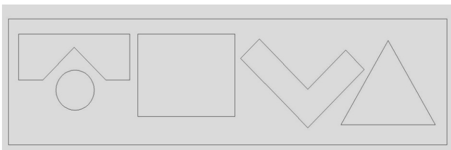
Where,

46 – Generated random number

99 – Orientational accuracy

Likewise the orientation of the parts has been obtained.

After obtaining the orientation of the part-1 it has been placed adjacent the part-2 such that the center points of the parts 1,2 lie in the same line and also it can be constrained that the boundary of the parts must not overlap by providing required bridge width (Refer Dwg.). It depends upon the cutting conditions. The other parts have been nested using the principle explained earlier.



3.2.Evaluation of the Utilization factor:

After nesting the parts for the given chromosomes, a rectangle has been drawn such it passes through the boundary of the nested parts with some clearance. And then the area of the irregular part and the rectangle has been found. The ratio between the area of the irregular part and the area of the strip is defined as the utilization ratio.

3.3.Steps in the Genetic Process:

Step1: Select the required part drawing.

Step2: Create initial population by generating the random number.

Step3: Evaluate the fitness values for each chromosome.

Step4: Create new population using proportionate selection scheme.

Step5: Generation random number corresponding to the new population.

Step6: Select the chromosome with cross over p_c and randomly fix the cross over point.

Step7: Mutate the chromosome (offspring) with the mutation probability.

Step8: Replace the offspring in the new population.

Step9: Sort the chromosome in ascending order and delete the chromosome having low fitness value.

Step10: Step4 to Step9 is continued up to the finite number of iteration.

4.Results and Discussions

However this proposed method would provide a best orientational arrangement for the given parts.. In this work, five irregular parts were taken. These parts were the inputs for the genetic algorithm. This process were executed and the results were obtained. It can be seen that the genetic algorithm gives the near optimum solution in less time. The percentage utilization of the sheet metal for this case up to 72%. It is clearly noted that the effectiveness of the nested pattern depends upon the geometry of the parts and orientation. This program is further converted into small fine steps and will be analyzed using VLSI Approach

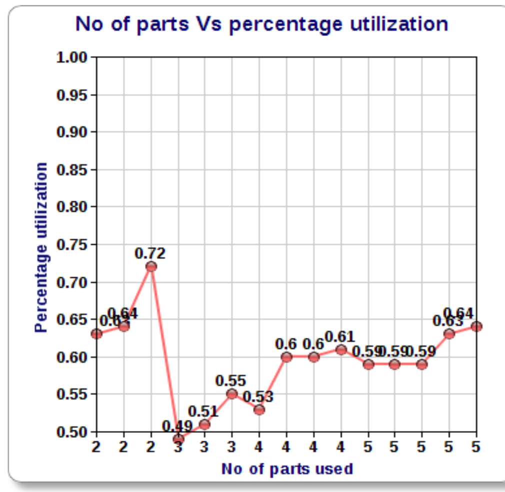


Table 1 No of parts Vs utilization ratio

Part used	Orientation	Initial population	Iteration	Cross .over prob.	Mutation prob.	Obj_ value
2	9	10	25	0.7	0.2	0.63
2	99	10	25	0.7	0.2	0.64
2	999	10	25	0.7	0.2	0.72
3	9	10	25	0.7	0.2	0.49
3	99	10	25	0.7	0.2	0.51
3	999	10	25	0.7	0.21	0.55
4	9	10	25	0.7	0.2	0.53
4	99	10	25	0.7	0.16	0.60
4	999	10	25	0.7	0.12	0.60
4	999	50	50	0.7	0.2	0.61
5	9	10	50	0.7	0.13	0.59
5	99	10	25	0.7	0.2	0.59
5	99	50	50	0.4	0.1	0.59
5	999	10	25	0.4	0.1	0.63
5	999	50	50	0.4	0.1	0.64

5. Conclusion

The proposed approach makes use of GA for nesting irregular shaped parts on the strip for the purpose of maximizing the utilization of sheet metal. It clearly denotes that the utilization factor increases to a certain extent with the increase in the orientation accuracy since it is a continues process for the researchers attains the as maximum results as by implementing the new techniques.

6. References

Gilmore,C.H.&Gomory,R.C.(1961),A Linear programming to the cutting stock problem, European J of Operational Research vol.9,pp. 724-746.

Gilmore, C.H & Gomory, R.C. (1965),A Multistage cutting stock problems for two and more dimensions, European J of Operational Research. Vol.13,pp. 94-120.

Gilmore,C.H& Gomory, R.C(1963),A Linear programming to the cutting stock problem, European J of Operational Research vol.11, pp.863-888

Adomowicz, M. & Albona, A. A two stage solution of the cutting stock, in information processing Proc. IFIP Congress (Amsterdam, North Holland), pp.1086-1091.

Nee, A.Y.C, (1984),Computer aided layout of metal stamping blanks, J of Engineering Manufacture,vol. 198, pp.187-194.

Al-hakim, L.(2000),A note on ‘A Genetic Algorithm approach’ for multiple criteria facility layout design, Int J of Production Research,vol.38(4),pp. 985-989.

Chow, W. W. (1979),Nesting of a Single shape on a strip,Int J of Production Research,vol.17 (4),pp. 305-322.

Eisemann, K. (1957),The trim problem, Journal of Management Sci,vol.3,pp. 279-284.

Haims,M.J&Freeman,H.(1970),A Multistage solution of the template layout problem,IEEE Trans Syst Sci Cybern, vol.6,pp.145-151.

Prasad, Y.K.D.V.(1995),A sliding algorithm for optimal nesting or arbitrarily shaped sheet metal blanks, Int J of Production Research,Vol.33(6), pp.1505-1520.

Nee,A.Y.C&Venkatesh,V.C,A(1984),Heuristic Algorithm for optimum layout of metal stamping Blanks, Annals of the CIRP,vol.33(1), pp. 317-320.

Albono, A & Sapuppo, G. (1980),Optimal allocation of two-dimensional irregular shapes using Heuristic search methods”, IEEE Trans on Syst Man & Cybern vol.10(5),pp.242-248.

Yan, Cao. (2006),Development of a sheet metal part stock layout system based on OPENCASCADE Platform, IEEE Trans on Computer & Computational Sci,vol

Kumaran Ramakrishnan.(2008),Solving two dimensional layout optimization problems with irregular shapes by using Meta heuristic, IEEE Int Con on Industrial Engineering and Engineering Management,pp.178-182.

Nye,T.J(2000),Stamping strip layout for optimal raw material utilization, J of Manufacturing Sys,vol.19(4),pp.239-247.

Hiroshi Murata(1996),VLSI Module placement based on Rectangle-Packing by the sequence –pair IEEE Trans comp.aided deign of IC and Sys,vol.15,pp.1518-1524.