OPTIMIZED SHIPYARD STEEL PLATE CUTTING PLAN BASED ON GENETIC ALGORITHM

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Abstract

As steel price is rocketing, an optimized steel plate cutting plan saves shipyard cost on raw material. In this paper, the author will use a hybrid algorithm to work out an optimum cutting strategy for irregular parts on multiple regular steel plates. The objective is to save cutting plan time and enhance steel use efficiency. Summarily the method employed here is, first convert the irregular parts problem to a simplified rectangular shape parts problem, then use Genetic Algorithm (GA) to schedule parts layout sequence, and finally apply improved bottom left (IBL) algorithm to place the part to a feasible location. Repeat the procedure until reach the satisfied objective function value.

Keywords: Bottom left algorithm, Genetic algorithm, Nesting, Steel plate cutting.

Introduction

The nesting of parts cut from steel plate has for many years been a subject of interest to the shipbuilder. An optimized steel plate cutting plan helps shipyard both time and material savings, increase production efficiency, in return enhance the company's competition capability.

In this paper, the author proposes a cutting strategy for irregular parts on multiple regular shape steel plates. The method is first simplify irregular shapes to regular shapes, and then use a hybrid algorithm, which combines improved bottom left algorithm (IBL) with genetic algorithm (GA), to find the optimum layout. IBL algorithm generates a nested pattern in the set of plates for the considered parts with the objective of utilizing the plate material efficiently. GA is to select an optimal sequence that the parts accommodate to the plates.

Jakobs [1] first combines GA and bottom left algorithms into a hybrid algorithm for optimal layout problem. However, Jakobs' bottom left algorithm is not able to fill out holes. Therefore, Liu and Teng [2] present an IBL and combine it with GA, achieving better experimental result. Yeung [3] and Tang [4] integrate GA and IBL to solve garment cutting and metal cutting problems respectively. Jiang [5] combined the adaptive simulated annealing GA with the IBL for the optimal layout problem of rectangle pieces. The algorithm developed in this paper can be used for rectangular parts into multiple rectangular plates.

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Irregular Shape to Rectangle

The shapes of parts in shipbuilding are most often close to non-convex polygons. In this case, the author first simplifies one irregular part to one polygon, and then randomly combines two polygons to form polygon nesting clusters. Finally replaces the polygon nesting clusters by rectangle nesting clusters. By this means, the irregular shape problem is able to transform to a regular shape problem.

Irregular to Polygon

Suppose any irregular part P, the steps for irregular to polygon are as follows:

Step 1. Choose a reference point $C_0(X_0, Y_0)$ on the part, where X_0 is the biggest value in x coordinate. Draw a line l_1 perpendicular to x coordinate cross the $C_0(X_0, Y_0)$ point, See Figure 1(a);

Step 2. Pivot on the reference point, counter-clock-wisely rotate line l_1 until the line touches any other point $C_1(X_1, Y_1)$ on the part. Record the rotate angle θ_1 and the distance d_1 between points C_0 and C_1, see Figure 1(b);

Step 3. Then pivot on point $C_1(X_1, Y_1)$, clock-wisely rotate the part at the angle of θ_1, so that $C_1(X_1, Y_1)$ becomes the rightmost point on the part, see Figure 1(c);

Step 4.Repeat Step 1, 2, 3 until reaching the finishing condition. The finishing condition is: assume $C_i(i = 1,2,3,\ldots)$ have been generated after Step 1, 2, 3. If $C_{i+1} = C_0$, then stop the process, and replace C_{i+1} by C_0, this means the part has already rotated 360^o and returns to its initial reference point;

Step 5. A polygon is thereafter created by drawing lines $d_i(i = 1,2,3,\ldots)$ subject to the rotate angle $\theta_i(i = 1,2,3,\ldots)$, see Figure 1(d).

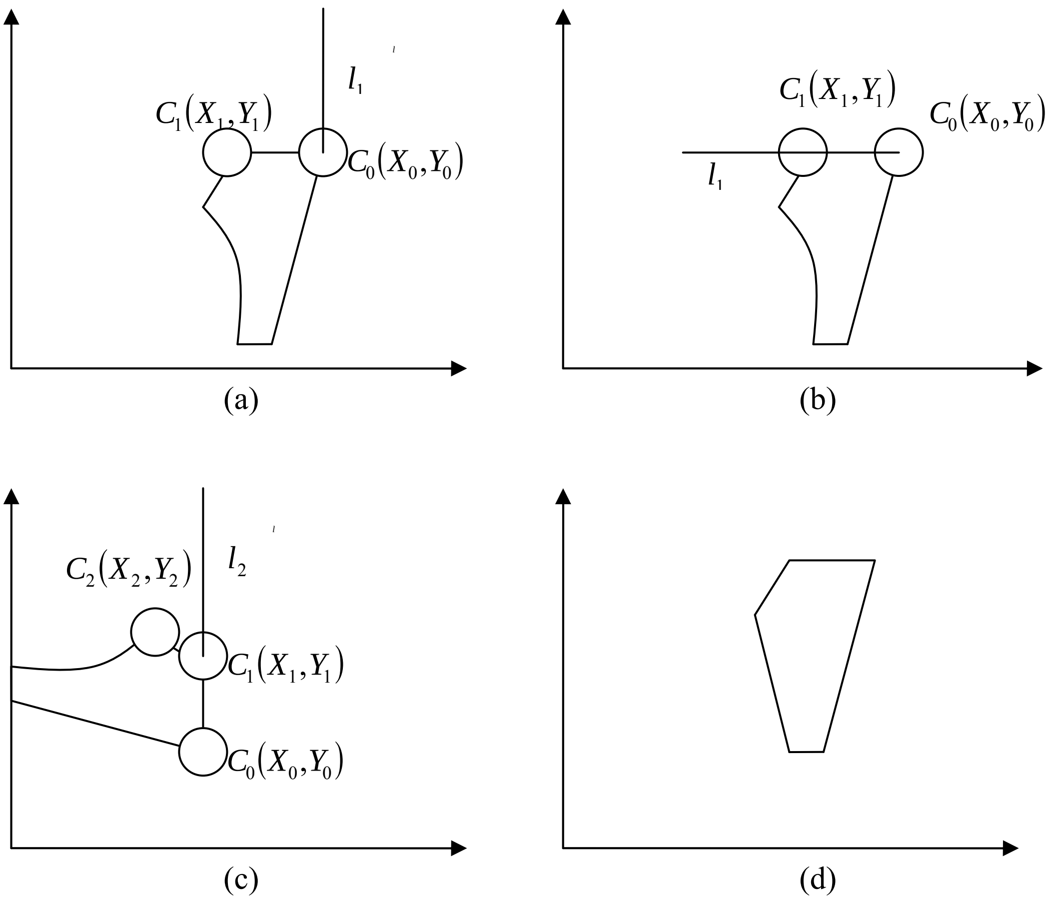

Figure 1. Draw polygon

Constitute Polygon Nesting Clusters

Although each part can be replaced by a minimum envelop rectangle, this kind of transform will inevitably waste many materials during cutting. Therefore, to minimize material waste, the author follows the method proposed by Grinde and Cavalier [6], randomly selects two polygons to form a so called polygon nesting cluster, and uses the minimum envelop rectangle of this polygon nesting cluster to replace the polygons. The steps for forming up polygon nesting clusters are as follows:

Step 1: Randomly select two polygon parts P_1 and P_2;

Step 2: Firstly, the author creates the envelop polygon. The envelop polygon can be obtained by rotating P_2 according to P_1, all the vertex of P_2 should have appeared on the boundary of P_1, i.e. there is no overlap between P_1 and P_2, as well as no separation.

Step 3. When the envelop polygon is created, it is certain that the best location of P_2 relative to P_1 must locate somewhere on the boundary of envelop polygon. The author sets the searching rule as to find the location on the boundary where the accordingly surrounding area of P_1 and P_2 within the envelop polygon is the minimum.

Step 4. Repeat Step 1 to 3 until all the polygon parts become polygon clusters.

Polygon Nesting Clusters to Rectangle Nesting Clusters

Finally, the author replaces polygon nesting clusters with its minimum envelop rectangle. As a result, the problem transformed from irregular shape to rectangle shape, easier for further layout planning.

Bottom Left Algorithm

Improved Bottom Left

Step 1. Always start placing parts from the bottom left corner of the rectangular plate. The part $I_j(1)$'s layout point is also its bottom left corner. Denote the plate bottom left corner coordinate as (0, 0), then lay out the bottom left corner of $I_j(1)$ at (0, 0);

Step 2. Since the allowable layout point (0, 0) is now occupied by $I_j(1)$, the author then deliberately sets this point's coordinate value to (-1,-1), means not allowable any more;

Step 3. After $I_j(1)$ is laid out on the plate, now $I_j(1)$ generates two additional allowable layout points (x_1, y_1) and (x_2, y_2), which are $(l_j(1), 0)$ and $(0, w_j(1))$, respectively, see Figure 2;

Step 4. Check allowable length *al* and allowable width *aw* for each allowable layout points, meanwhile evaluate the effect of new part on the allowable points, see Figure 3. Store all the information in an array TP.

Step 5. Search in TP, find feasible allowable layout points for $I_j(2)$, satisfying $x \neq -1$ and $y \neq -1$, $l_j(2) \leq al$ and $w_j(2) \leq aw$;

Step6. Determine the final layout point subject to following preferences: the first preference is downward moving, i.e., layout the part as bottom as possible; the second preference is leftward moving, i.e. when both allowable layout points have the same height, always choose the left one.

Step 7. Repeat Step 2 to 6 until all rectangular pieces are laid out completely.

The detailed layout process is shown in Figure 4.

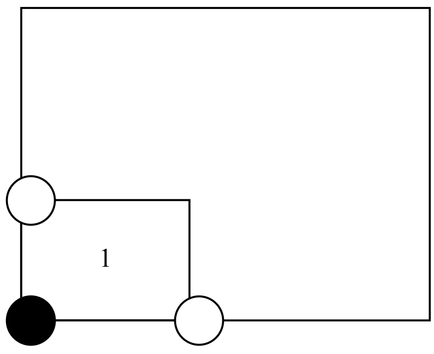

Figure 2. Allowable points

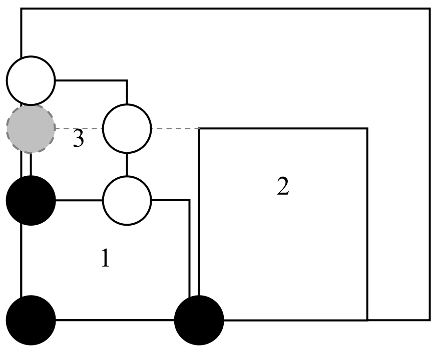

Figure 3. Check allowable points

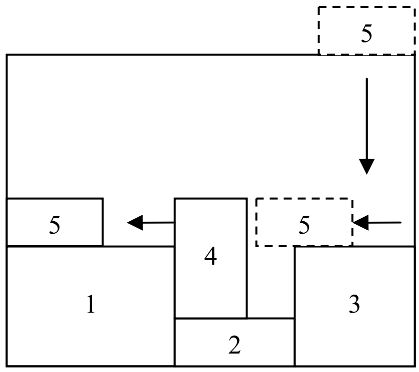

Figure 4. IBL Layout

Objective Function

The objective function only associates with utilization. The utilization means the ratio of the sum area of rectangular parts to the total area of the rectangular plate, i.e.

$$\begin{cases} U = \dfrac{\sum_{i=1}^{n} l_i \times w_i}{L \times W} \\ s.t. \begin{cases} x_i \geq 0 \\ y_i \geq 0 \\ x_i + l_i \leq L, y_i + w_i \leq W \quad if\theta = 0^o \\ x_i + w_i \leq L, y_i + l_i \leq W \quad if\theta = 90^o \end{cases} \end{cases} \quad (1)$$

Where:

l_i, w_i denotes the i[th] part's length and width respectively;

L, W denotes the plate's length and width respectively;

x_i, w_i denotes the i[th] part's bottom left point coordinate;

θ denotes the angle of rotation of the i[th] part, $\theta \in \{0^o \quad 90^o\}$;

n denotes the number of parts in the plate.

According to this definition, the problem can be described as: achieving layout optimization under the constraints in order to achieve the maximum utilization ratio U of rectangular plate, i.e. max U.

Genetic Algorithm

Selection

The next generation is constituted by the combination of children and elitists. Children are evolved from parents, while elitists are directly selected from the current population on a rank-based selection model. Rank-based selection model focuses on individual fitness value, and there is no requirement for the value difference level between individual fitness. The steps are as follows:

Step1. Sort all the individuals in the population according to the fitness in a top-down rank;
Step2. Determine an elitist population size PE;
Step3. Select the best PE individuals for the next generation.

However, the consideration for parents' selection includes the value difference level between individual fitness. The steps for parent selection are as follows:

Step1. Sum up all individuals' fitness value SUMF;
Step2. Compute the selection probability of each individual as in below formula,

$$P(i) = \frac{\sum_{j=1}^{i} fitness(j)}{SUMF} \qquad (2)$$

Step3. Generate a random value R, choose the i[th] individual as parent whose selection probability P(i) is most approximate to R, and satisfies R<P(i).

Rotation

Rotation is one of the methods for new individual generation. The steps of rotation are as follows: firstly, randomly generate a number P_R to indicate the location where rotation begins; secondly, advance the genes at and behind the rotation location to the first, and follows by the genes before the rotation location.

For example, $I_1 = \{1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6\}$, if $P_R = 3$, then $I_1^{'} = \{3 \quad 4 \quad 5 \quad 6 \quad 1 \quad 2\}$.

Mutation

Mutation is the method to determine which part whose code is the gene will rotate at an angle of 90^o. The steps are as follows: firstly, generate a random number P_M to indicate the location which gene will mutate; then change the gene by plus the chromosome size to indicate the part whose code is this gene to rotate at an angle of 90^o.

For example, $I_1 = \{1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6\}$, if $P_M = 3$, then $I_1^{'} = \{1 \quad 2 \quad 9 \quad 4 \quad 5 \quad 6\}$.

Interchange

Interchange is another method to generate new individual. The steps of interchange are as follows: Firstly, generate two random numbers P_{C1} and P_{C2}; then exchange the genes at locations P_{C1} and P_{C2}.

For example, $I_1 = \{1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6\}$, if $P_{C1} = 3$, $P_{C5} = 5$, then $I_1^{'} = \{1 \quad 2 \quad 5 \quad 4 \quad 3 \quad 6\}$.

Fitness Function

The objective function is only associated with steel plate utilization, therefore, the fitness function can be indicated as:

$$f(I_j) = \frac{\sum_{k=1}^{m} U(k)}{m} + \frac{w}{m^2 \times \sqrt[m]{\prod_{k=1}^{m} U(k)}} \qquad (3)$$

Where:

U(k) is the k[th] plate's utilization;

m is the number of plates whose utilization is nonzero;

w is weighted coefficient, in this paper the author choose as 0.001.

The first part of this fitness function is to figure out the maximum utilization of one particular plate, and the second part is to make sure parts placed most compactly when allocate to several plates.

Once the layout sequence of rectangular parts is determined, heuristic algorithm will be used to compute the value of objective function U(k) using formula (1), and the formula (3) will be used to compute the corresponding fitness value of this individual.

Case Study

To verify the hybrid algorithm in this paper, the author selects verification problem in reference [7] as the test case for illustration purpose. The rectangle parts are given in table 1.

Part Size	Qty	Part Size	Qty
12.5×15	1	15×7.5	3
12.5×10	1	7.5×7.5	3
17.5×15	1	5×5	3
12.5×7.5	1	5×12.5	4
15×5	1	7.5×5	6
10×10	2	5×10	8
15×10	2	7.5×10	14

Table 1. Different sizes of rectangular parts in reference [7]

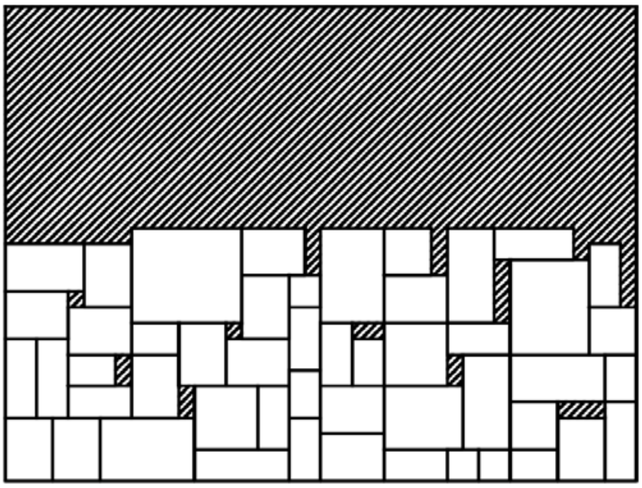

Figure 5. Optimum layout plan from reference [7]

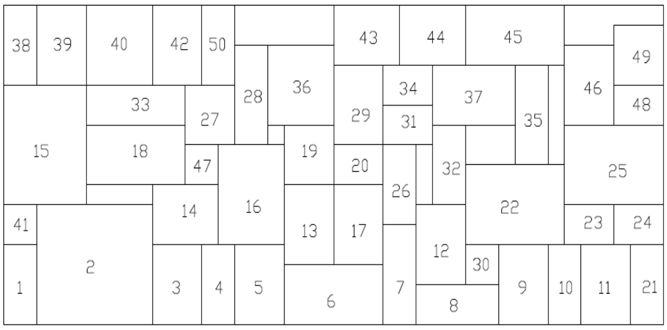

Figure 6. Optimum layout plan by 1000 Generations

Both methods are able to allocate all the parts in a 100×40 rectangular area. The method proposed in this paper yields 93.75% utilization, the same as the utilization in reference [7], thus verified the algorithm.

Conclusion

The optimal nesting problem for steel plate is of far-reaching importance in shipyard practice. In this paper, the author simplifies irregular shape parts to rectangle parts by means of polygon nesting clusters, meanwhile, a hybrid algorithm combined GA and IBL is presented. The test cases yields satisfied result. This method can be further explored for practical application.

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