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Application of the Group Decoder for Solving the Orthogonal Materials Cutting Problem

Rustam Abubakirovich Fayzrakhmanov, Rustam Talgatovich Murzakaev, Aleksey Sergeevich Mezentsev and Vadim Sergeevich Shilov

Perm National Research Polytechnic University, Perm, Russia

Abstract: The algorithm - decoder for solving the orthogonal materials cutting problem is suggested in the article. The heuristic rule of selecting the order, in which the parts are recommended to input into the developed algorithm has been defined. It has been suggested to use the metaheuristic methods of the combinatorial optimization to improve the algorithm - decoder operation. The simulation experiments, which show, that the proposed algorithm allows finding better solutions than the existing equivalents and sometimes the found solution is an optimal one, have been conducted.

Key words: Cutting and packing problem · Decoder · Metaheuristics · NP · Dynamic programming

INTRODUCTION

The nesting problem is one of the most frequently emerging production problems. A lot of works [1-5] devoted to the resource-saving and especially materials cutting problems reflect the high academic interest in this class of problems. The class of the cutting and packing problems relates to the NP-hard problems, i.e. today the exact solution algorithm which solves them in the polynomial time has not been developed. Although a lot of scientific works, in which the methods resulting in reasonably good solutions are discussed, are devoted to the cutting problems solution, a search for new algorithms of the approximate solution has been still a crucial task. The 2D material nesting problem consists in finding the sheet material cutting chart which allows getting all required parts and at the same time minimizing waste [6].

If in the cutting problem the required parts and sheet materials are orthogon in shape, then the problem is referred to orthogonal cutting. An orthogon is the most standard shape, which very often occurs at the place of production, thus the orthogonal cutting problems is an important subset of the cutting problems.

The objects could be allocated both on the orthogonal sheets, for which the material length and width are set and on the semiinfinite strip, for which only width is set. In the former case it is necessary to minimize the number of the used sheet materials, in the latter case - to minimize the occupied area. The occupied area will be estimated using the formula $S_3 = W \times x_{max}$, where W- is a strip width, x_{max}- is a maximum coordinate of OX from all the allocated objects [7]. The concept of the effective area ratio will be used for more clear evaluation of the performance of the algorithms of the objects' allocation on the semi-infinite strip: $k_S = \frac{S_n}{S_3}$, where $S_п$- is an effective area, which is defined as a sum of all the objects' areas.

Application of the Decoders for Solving the Orthogonal Materials Cutting Problem. A lot of heuristic methods are developed for solving the orthogonal materials cutting problem. The most interesting ones among them are the algorithms - decoders. These algorithms allocate the objects according to a heuristic rule and a priority list. The priority list sets the order of the objects' allocation on the sheet material. This list could be exactly determined by the algorithm - decoder, the problem requirements or received by the metaheuristic methods of the combinatorial optimization, such as the genetic algorithm or the simulated annealing method [8, 9].

Let's consider some existing decoders for the detection of its weakness.

Corresponding Author: Rustam Abubakirovich Fayzrakhmanov, Perm National Research Polytechnic University, Komsomolskiy Avenue, 29, 614090, Perm, Russia.

Sub (NF) Substitution Decoder, Next Fit: Sub(NF) Decoder is a block-structured modification of the simple NF (Next Fit) heuristics. It allocates the orthogons sequentially by the NF algorithm, according to the priority list π, substituting free space between the orthogons in the blocks. If the next orthogon does not fit to the stated free space in the block, then it is placed above the current free space or into the next block [6].

Sub(NF) Decoder complexity $O(m^2)$, where m - is a number of parts [6].

Sub (FF) Substitution Decoder, First Fit: The decoder allocates the orthogons sequentially by the FF algorithm. Unlike Sub(NF), where we find an appropriate block for the next orthogon, where it suits the height, Sub(FF) finds the first of π appropriate orthogon for the given free space in the block. And only if no one orthogon suits, Sub(FF) proceeds to the next free space [6].

Sub(NF) Decoder Complexity $O(m^2)$ [6].

Greedy Sub Greedy Substitution Decoder: The Greedy Sub Decoder is a heuristic packing method upon the block-structured Substitution Decoder. This decoder picks the next orthogon so that it maximally suits the current block. In case of the equality of some orthogons heights the choice is made according to the priority list.

GreedySub Decoder Complexity $O(m^3)$ [6].

The examined decoders help to find reasonably good solutions. However free spaces could occur on the sheet as they operate particular objects. Thus a decoder which fills it by the objects groups has been developed, what allows maximum using of the current block under consideration. This decoder is suggested to be called the group one, as it operates the objects groups.

Group Decoder. The objects group is chosen so, that its total height will maximally suits the height of the current block, but does not exceed it. This problem is similar to the knapsack problem [10, 11], which has a pseudopolynomial solution algorithm upon the dynamic programming with asymptotics $O(nW)$, where n - is a number of objects, W - is the maximum permissible weight. However in this case you must consider that the allocated object has two dimensions and could be rotated by 90 degrees.

Let's introduce the following notations:

- H - is the height of the current block under consideration;
- m - is a number of still non-allocated objects;
- h - is the current total height;
- k - is a number of the examined objects;
- $l[k]$ - is the length of the k – го object;
- $w[k]$ - is the width of the k – го object;

$f(h, k)$ function characterizes the state attainability, it could be defined out of the following recursion relation.

$$f(h,k)=\begin{cases} False, & h<0, \\ False, & h\neq 0 \;\; k=0, \\ True, & h=0, \\ f(h-l[k],k-1)Vf(h-w[k],k-1) & \\ \quad Vf(h,k-1) & k>0 \;\; h>0 \end{cases}$$

The function outputs f will be stored in a file, what allows, firstly, non-calculating the function values from the same arguments several times, secondly, restoring the problem solution by backward driving through this file.

Thus, the Greedy Sub Substitution Decoder could be modified, its scheme is represented in [6]. Modify it subject to the suggestions made.

Algorithm Scheme:

- (Initialization)

Input Data <H, W, n, l, w, π>
Current Vertical Block C = 1

- (Iterations)

Perform 2.1-2.3 until all the orthogons have been packed.

Cycle through free spaces in the vertical block C (bottom-upwards)
Find the objects group, which maximally fills the free space.
If you have found it, then:

- Insert the obtained group of orthogons;
- Calculate the length l_{min} of the shortest orthogon in the block C.

Modify the block structure so that the block length C will be l_{min}.

End of Cycle

C=C+1

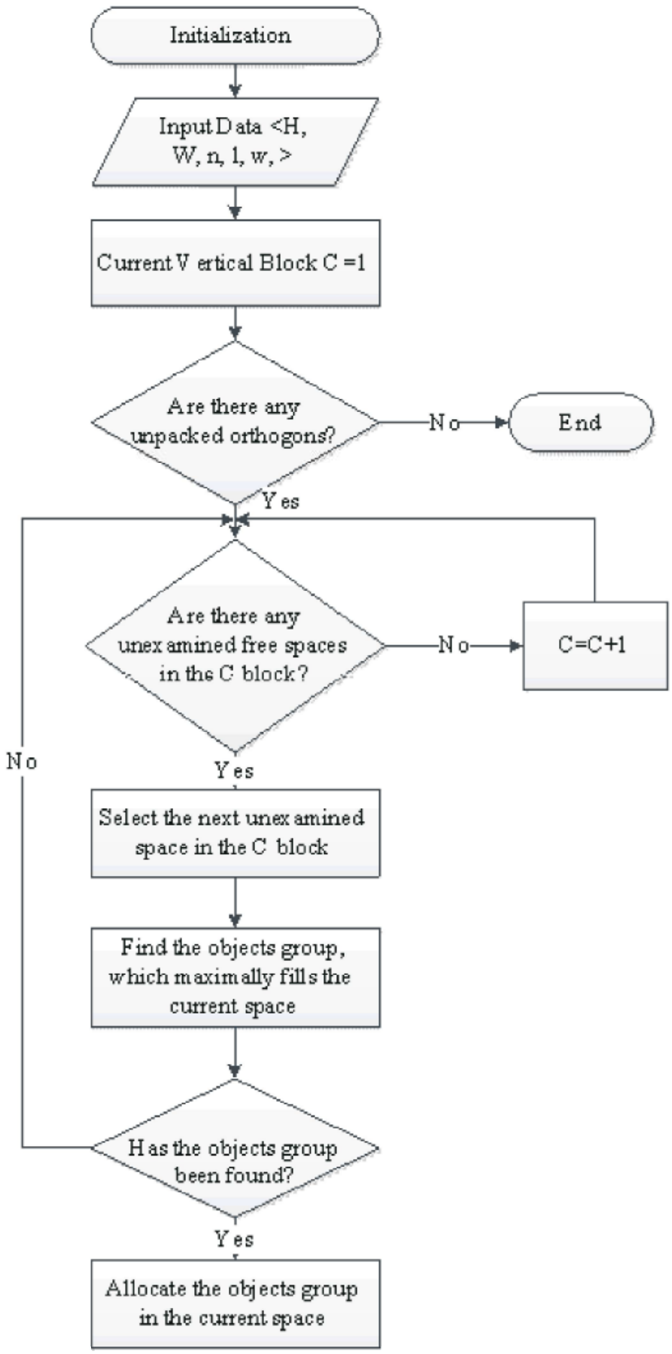


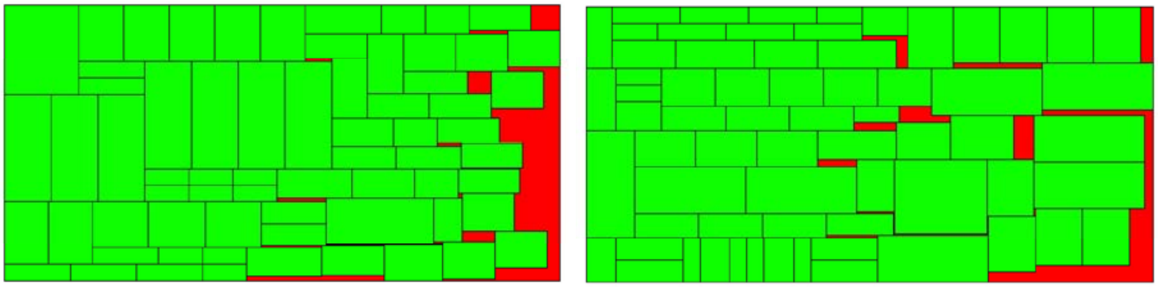
Fig. 1: Flow Diagram of the Group Decoder Operating Procedure

Output of the Found Solution: The flow diagram is represented on the Fig. 1.

Upon the objects' allocation on the sheet materials it is also necessary to ensure that the end of the sheet has not been reached, if no more objects could be allocated on the current sheet, then proceed to the next one.

The decoder complexity is $O(Wn^3)$, which is worse than one of the examined above decoders, but this decoder is expected to find substantially better solutions.

The solution obtained by the decoder depends heavily on the order of the objects' allocation on the sheet material. It is proposed to use the metaheuristic methods of the combinatorial optimization, such as the genetic



(a) (b)

Fig. 2: Cutting charts, received using the Group Decode (a - without the simulated annealing method, b - with the simulated annealing method)

algorithm or the simulated annealing method, for the determination of such order. When writing this article the tests with the simulated annealing method were conducted.

When performing the tests on the group decoder; it was found that presorting the parts by its area (thus, the largest parts were allocated firstly) could also considerably improve the obtained result.

Simulation Experiments: The software which solves the problem using all the examined methods, was developed to compare the proposed algorithm - decoder with the existing ones. The algorithms were evaluated both alone and with the simulated annealing method. The tests on the problem of the objects' allocation on the semiinfinite strip were conducted. The effective area ratio was used as a criterion.

The example of the cutting charts, received using the Group Decoder, is represented on the Figure 2. On the figure the allocated parts are highlighted in green, the free area is highlighted in red.

As shown on the represented figures, the proposed decoder provides the reasonably dense objects' allocation.

Two groups of the initial data were generated to perform the algorithm tests on the data sets, which are dimensionally similar to the real ones. Each set of data consisted of 5 tests. For the first group the width of the sheet material was set to 1000, a number of the parts was - 400, the length and the width of the parts were - from 50 to 200. For the second group the sheet material with the dimensions of 1500õ6000 was divided into orthogons at random, after that the problem of the orthogons allocation on the semiinfinite strip with width of 1500 was solved. Thus, the algorithms performance on the set of the parts, which could be allocated so that the effective area ratio will be equal to 1, was evaluated. Before all the tests the sets of the parts had been sorted by its area.

The results of the algorithm tests on the first data group are represented in the Table 1.

In this table and the tables below # symbol denotes the test number.

The algorithm names are represented in the columns, the test numbers - are represented in the rows. The algorithms performance has been evaluated according to the effective area ratio.

The algorithms have the following notations:

- Sub (NF) – is the "Next Fit" Decoder;
- Sub (FF) – is the "First Fit" Decoder;
- GreedySub – is the GreedySub Decoder;
- GroupSub – is the Group Decoder;
- Sub (NF)+SA – is the "Next Fit" Decoder with the simulated annealing method;
- Sub (FF)+SA – is the "First Fit" Decoder with the simulated annealing method;
- GreedySub+SA – is the GreedySub Decoder with the simulated annealing method;
- GroupSub+SA – is the Group Decoder with the simulated annealing method;

As shown on the Table 1, the Group Decoder, used with the simulated annealing method provides the best solution.

The results of the algorithm tests on the second data group are represented in the Table 2.

The Group Decoder, used with the simulated annealing method, also provided the best solution on the second data group and during two tests an optimal solution was found.

Table 1: The results of the algorithm tests on the first data group

#	Sub(NF)	Sub(FF)	GreedySub	GroupSub	Sub(NF)+SA	Sub(FF)+SA	GreedySub+SA	GroupSub+SA
1	0.911	0.890	0.943	0.962	0.894	0.943	0.968	0.978
2	0.908	0.911	0.938	0.960	0.890	0.950	0.955	0.964
3	0.935	0.909	0.945	0.968	0.918	0.943	0.964	0.973
4	0.928	0.897	0.941	0.964	0.904	0.945	0.967	0.973
5	0.914	0.897	0.929	0.950	0.902	0.951	0.948	0.963

Table 2: The results of the algorithm tests on the second data group

#	Sub(NF)	Sub(FF)	GreedySub	GroupSub	Sub(NF)+SA	Sub(FF)+SA	GreedySub+SA	GroupSub+SA
1	0.840	0.850	0.926	0.997	0.926	0.958	0.974	0.997
2	0.870	0.870	0.917	0997	0.932	0.955	0.983	0.997
3	0.862	0.888	0.938	0.997	0.943	0.968	0.987	1
4	0.829	0.885	0.929	0.974	0.926	0.968	0.974	1
5	0.865	0.857	0.952	0.997	0.926	0.958	0.977	0.997

CONCLUSION

The algorithm - decoder for solving the orthogonal cutting problem and its modification using the simulated annealing method were suggested in the article.

Conclusions:

- The performed tests have shown, that this algorithm finds better solutions than the other examined algorithms.
- It has been found, that he parts are recommended to input into the algorithm being sorted by its area, thus, the large parts would be allocated first. This order will not be optimal for the Group Decoder, but it is one of the best ones. It is recommended to use the metaheuristic algorithms, especially the simulated annealing method for searching the best parts order.
- Although the asymptotics of the Group Decoder $O(Wn^3)$ is worse than the asymptotics of the other algorithms - decoders, its execution time even with the simulated annealing method on the data, which are dimensionally similar to the real ones, compares with the other examined algorithms execution time.

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