Computers & Industrial Engineering 80 (2015) 111–124

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Heuristic and genetic approach for nesting of two-dimensional rectangular shaped parts with common cutting edge concept for laser cutting and profile blanking processes

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ARTICLE INFO

Article history:
Received 12 December 2013
Received in revised form 17 November 2014
Accepted 20 November 2014
Available online 27 November 2014

Keywords:
Two-dimensional nesting
Genetic algorithm
Sheet metal cutting
Laser beam cutting
Sheet metal blanking

ABSTRACT

This paper presents a novel two-dimensional nesting strategy suitable for sheet metal industries employing laser cutting and profile blanking processes. The proposed nesting approach is developed by the combination of heuristic and genetic algorithms in order to generate an effective nested pattern, in such a way that, it minimizes the sheet material wastage and also the cutting tool path distance, while arranging a set of rectangular parts in a rectangular sheet. With the proposed bottom–left heuristic method, at first, the parts are considered in a specific sequence and orientation, and each part is translated to the feasible bottom left most position on the previously placed parts and then adjusted to form the common cutting edges with adjacent parts. Further, the heuristic algorithm ensures the formation of clusters, in which a group of parts share the cutting edges, for effective handling of parts while cutting. Finally the optimal and effective nested pattern is generated by the genetic evaluation process which reproduces several sets of nested patterns, before converging to the optimality. The effectiveness of the proposed work, in terms of utilization of sheet material, is demonstrated by comparing the results obtained from the literature. Furthermore the uniqueness of the present approach in enhancing the nested pattern efficiency and minimizing the tool path distance with common cutting edge concept is illustrated.

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1. Introduction

With increasing demand for complex geometrical sheet metal products in various applications such as machine tools, automobiles, railways, aircrafts, air conditioners, generators, switch gears, metrological equipments, electronic devices, furniture, kitchen utensils etc., sheet metal machinery manufacturers are exploring effective solutions to produce the sheet metal components with targets of higher productivity, utmost precision, lower manufacturing cost and less material wastage.

Typically, sheet metal components are produced with an initial process of cutting two-dimensional geometrical profiles (referred as unfold patterns or blanks) from a large rectangular sheet through blanking or laser cutting or combination of these processes. Subsequently, these two-dimensional blanks are subjected to bending process, to produce three dimensional components. Finally, these sheet metal components are assembled into products. In this context, an effective CAM system integrated with machinery makes the process more intelligent in utilizing the material, process, tools, operator effort etc.

Focus of the present paper is to investigate an effective CAM system for sheet metal cutting processes with the objectives of increasing material utilization and minimizing the cutting time. Generally two-dimensional sheet metal blanks are produced by blanking or laser cutting processes. Fig. 1 shows the different shaped parts produced by blanking, profile blanking and laser cutting processes. It can be noted that, the simple and regular geometrical shapes are blanked using appropriate punch and die set. Whereas the complex and irregular geometrical shapes are cut by profile blanking or laser cutting processes. Profile blanking process is suitable to produce linear edged profiles by means of blanking along the profile using punches of rectangular cross-section (Fig. 1b). Laser cutting process is employed for cutting of complex shapes including linear and curvilinear edges.

From the above discussion it is clear that, the two-dimensional shapes have to be arranged on a sheet, prior to cutting, as closely as possible, and this is known as nesting process. Generating the optimal nesting layout with the aim of minimizing the wastage of sheet material and thereby arranging the geometrical shapes accordingly, is a very important task in sheet metal industry, as

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http://dx.doi.org/10.1016/j.cie.2014.11.018
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even a small amount of savings on each sheet material, has a significant impact on total material cost. Since the geometry of parts to be cut may vary from simple rectangular shapes to highly complex profiles, and the quantity of the parts to be cut falls under a wide range, considerable effort is required to obtain the optimal nested pattern. Further, the two-dimensional nesting process known to be the NP hard in nature, that means, the possible ways to arrange the parts (search space) increases exponentially with the quantity of parts and their geometrical complexity (Zheng, Ren, Ge, Qiu, & Liu, 2012). To address such two-dimensional nesting problems, several attempts have been made by researchers for the past three decades and several algorithms have been proposed with the consideration of geometrical complexity of parts. However, much attention has not been given to arrange them in a manufacturing perspective. Without considering the manufacturing parameters, generating the nested pattern merely based on geometry does not make sense and is not be an effective, either. Hence the present work focuses on addressing the nesting algorithm to generate the optimal nested pattern, suitable for profile blanking and laser cutting processes, by considering part geometry as well as cutting process requirements. Since the major contribution in this work is to propose an effective nesting algorithm from a manufacturing perspective, geometry of the parts is restricted to rectangular shape for an easy demonstration.

2. Review of rectangular nesting algorithms

To address nesting of rectangular parts in rectangular sheets, several researchers have proposed different methods employing heuristic algorithms in combination with Artificial Intelligent methods such as Genetic Algorithm, Simulated Annealing algorithm, Naive Evolution (NE), Hill Climbing and Tabu Search. Heuristic methods are fixed deterministic approaches which follow certain strategy while arranging parts in the sheet. Many rectangular geometry specific methods consider the rectangular parts in sequential manner with possible orientations of either 0° or 90° and arrange them on the sheet as close as possible. Whereas, the role of AI methods is to explore the best sequence and orientation of parts with the help of a heuristic method that produces the optimal nested pattern to utilize the sheet metal effectively. The different heuristic strategies proposed by researchers are explained with a simple example as given in Fig. 2. In this example, for each nested pattern, it is shown that the first seven parts are placed as per heuristic strategy addressed in literature and details of the positioning strategy are explained for the 8th part.

Jakobs (1996) proposed a *bottom–left* heuristic algorithm (Fig. 2a), by considering the parts in a sequential order to arrange them on a single rectangular sheet. Each part in the sequence is moved from the top-right corner of the sheet towards bottom until it touches the boundary of the previously placed part(s) or sheet. Then the part is moved towards left until it touches the boundary of the previously placed part(s) or sheet again. In this manner, movement of parts continues till the part cannot move further bottom or left. The final position is known to be the bottom–left position. The Bottom left directional movement of the 8th part is shown in Fig. 2a with *dotted lines*. In a slightly different heuristic approach (Fig. 2b) proposed by Liu and Teng (1999), the part slides along the boundary of previously placed parts in bottom–left manner. As shown in Fig. 2b, part 8 moves down first and slides along the edge of the part 6, then moves down till it touches top edge of part 3. Further it slides left until it touches part 5, which can be seen as the final possible bottom left position.

In contrast to moving the parts in bottom left directions, while nesting them on a sheet, Babu and Babu (1999, 2012) proposed a method (Fig. 2c) in which parts are translated directly to the predefined positions known as nodes. The nodes are calculated after placing each part, by projecting imaginary lines from top right corner of the part towards bottom left directions on previously placed part(s)/sheet boundary. From the available nodes, the next part in the sequence, for example, 8th part, occupies bottom left most node at which the part does not overlap with other parts. Similarly, the bottom–left strategy proposed by Hopper and Turton (1999, 2001), identifies several empty rectangular spaces among the previously placed parts (Fig. 2d). The subsequent parts are placed on bottom left most possible empty rectangular space. Yet another method by Leung, Zhang, and Sim (2011) quantified the empty rectangular spaces as pockets and represented them with parameters such as position ($x1$, $y1$), width (w), height of the left wall ($h1$) and height of the right wall ($h2$) as shown in Fig. 2e. Each pocket is evaluated for the positioning of the next part with a set of rules (Leung et al., 2011). For example, 8th part in the sequence is placed at the pocket, whose dimensions are closer to that of the part.

Burke, Kendall, and Whitwell (2004) proposed the Best-Fit heuristic, to arrange the parts on a sheet based on the *skyline* concept (Fig. 2f). Skyline is a contour of lines drawn from the top most edges of previously placed parts. The height of the skyline for each incremental distance along the width of the sheet, (x-axis), is represented in Fig. 2f. For example, the height of the 1st sky line segment is 5 units and its starting position is 0. To place a part on the sheet, it is translated to the starting point of the skyline segment, whose height is minimum. For example, the 8th part is placed on the 4th skyline segment (Starting position = 11. Height = 2), i.e., at position $P(11, 2)$. Wei, Oon, Zhu, and Lim (2011), proposed an improved version of the skyline based method (Fig. 2g), in which each skyline segment is evaluated with several parameters such as "the exact fit on the selected skyline segment", "the local wastage produced after placing the part" etc., before choosing the criteria to place a part. For example, 8th part is placed at which the local wastage is minimum (Fig. 2g).

In contrast to the above bottom–left heuristic methods, Binkley and Hagiwara (2007) proposed a *four corners'* heuristic, in which the parts are placed at all the four corners of the sheet as shown in Fig. 2h. In this approach, at first, the parts are considered in a sequence and divided into four sub-sequences. The parts from each sub-sequence are positioned on each one of the corners of the sheet.

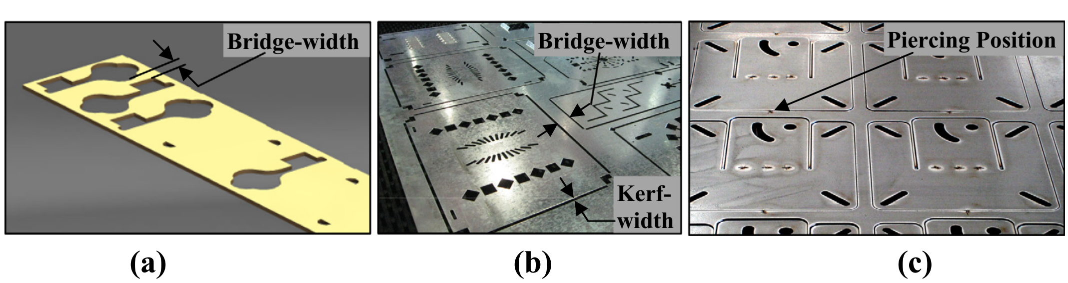

Fig. 1. Different geometrical shaped parts produced with (a) blanking, (b) profile blanking, and (c) laser cutting processes.

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