Journal of Manufacturing Systems 33 (2014) 624–638

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Sequential optimization approach for nesting and cutting sequence in laser cutting

S. Umar Sherif[a], N. Jawahar[b,*], M. Balamurali[b]

[a] K.L.N. College of Information Technology, Sivagangai 630611, Tamil Nadu, India
[b] Thiagarajar College of Engineering, Madurai 625015, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form 18 May 2014
Accepted 30 May 2014
Available online 28 June 2014

Keywords:
Laser cutting
Sequencing
Nesting
Optimization
Simulated annealing algorithm
Heuristics

ABSTRACT

The economy of the laser cutting process depends on two productivity issues: (i) nesting, a classic problem of finding the most efficient layout for cutting parts with minimum material waste; (ii) cutting sequence, which targets the optimal sequence of edges of the parts to be cut for minimum cycle time. This paper presents a two stage sequential optimization procedure for nesting and cutting sequence for the objectives of maximizing material utilization and minimization of ideal (non-cut) travel distance of laser cut tool. However, the focus of this paper is the development of solution technique for optimal cutting sequence to any given layout. Simulated annealing algorithm (SAA) is considered to evolve the optimal cutting sequence. The proposed SAA is illustrated with the optimal material utilization layout obtained using sheet cutting suite software, a professional rectangular nesting software package. The robust test carried out with five typical problems shows that the SAA proposed for cutting sequence is capable of providing near optimal solutions. The performance comparison with two literature problems reveals that the proposed SAA is able to give improved result than GA and ACO algorithms.

1. Introduction

Complex sheet metal parts are produced from the blanks that are obtained by laser cutting or blanking. The blanking operation is used for mass production of parts with identical shape, while the laser cutting process is used for production of complex parts with different profiles in single and medium lots. Material utilization and cutting sequence are the two prime factors that govern the production efficiency and production cycle time, and thereby the cost of laser cutting process. On these considerations the studies on laser cutting mainly address the following two productivity related issues: nesting and cutting sequence. Nesting is a classic problem of finding the most efficient layout for cutting parts with minimum material waste. The nesting is characterized by the intrinsic difficulty of dealing with geometry, satisfaction of the no-overlapping and containment constraints and complex computation [1]. Operators decide the layout from their experience, but this is not an efficient method because it is time consuming and the results do not efficiently utilize the raw material. It is challenging to obtain an efficient solution in a reasonable time when there are a large number of parts. Nesting is an NP-hard problem and an optimal solution is impossible to calculate in a timely manner [2]. Currently there is still lack of practical algorithms in industry to nest complex and multiplex parts. But several researchers have attempted to develop methods for nesting rectangular shaped parts on rectangular sheets. Most of the nesting algorithms are limited to regular blank shapes such as rectangles or simple polygon shapes. When the blank shapes are irregular, initial conversion to approximate rectangular shapes are performed before the nesting process [3,4]. In today's manufacturing challenges, the role of software is even increasing in importance. The market has been flooded with several nesting software with different capabilities. The focus of nesting software is maximizing material utilization and improving processes and flexibility. On the other hand, cutting sequence targets the optimal sequence of edges of the parts to be cut for minimum cycle time. The objective of cutting sequence is to find the shortest path for cutting all the edges of parts. The total travel distance of laser cut tool includes cutting and non-cut (ideal) moves. Normally the cutting distance is independent of the orientation of the parts (i.e. layout), but the ideal travel distance of laser cut tool depends on the layout and influences the total travel distance of tool. Hence the minimization of non-cutting length is most often considered as the objective to minimize the total cutting time required for cutting. When the laser cutting is used for drilling (laser drilling), the problem can be considered as Travelling Salesman Problem

* Corresponding author. Tel.: +91 9894329638.
E-mail addresses: sherif.umar@gmail.com (S.U. Sherif), jawahartce@yahoo.co.uk, jawahartce@tce.edu (N. Jawahar), balacim82@tce.edu (M. Balamurali).

http://dx.doi.org/10.1016/j.jmsy.2014.05.011
0278-6125/

Nomenclature

$a_{ix}{}^0$	X co-ordinate value for start point (0) position of edge 'i'
$a_{ix}{}^1$	X co-ordinate value for end point (1) position of edge 'i'
$a_{iy}{}^0$	Y co-ordinate value for start point (0) position of edge 'i'
$a_{iy}{}^1$	Y co-ordinate value for end point (1) position of edge 'i'
d_1	ideal travel distance between home position and first edge in sequence
d_2	ideal travel distance between first edge and second edge in sequence
d_3	ideal travel distance between second edge and third edge in sequence
I	identifier for edge
ITD	ideal travel distance
ITD_g	ideal travel distance of global string
ITD_{opt}	ideal travel distance of optimum string
ITD_p	ideal travel distance of perturbed string
n	number of edges present in the layout
Pa	probability of acceptance
T_f	final temperature
T_i	initial temperature
U	random decimal number between 0 and 1
W	width of standard sheet
X	randomly generated cutting sequence
X_g	global cutting sequence string
X_{opt}	optimum cutting sequence string
X_p	perturbed cutting sequence string
Z	temperature reduction factor
ΔE	change in entropy
SD	standard deviation

(TSP) by treating the holes as the locations to be visited and tool as the salesman. However, the different edges of the blanks in laser cutting cannot be considered as points and the cutting tool is constrained to follow the two ends of the edge successively together for cutting to be done. Hence it may be considered as constrained TSP [5,6]. Khan et al. [7] considered path optimization between irregular parts using start and end constraints. They represented the irregular parts as cells with possible start and end point and used simulated annealing algorithm (SAA) to solve the problem. Han and Na [5] also used the concept of cells to develop an algorithm for torch path optimization during laser cutting of nested stocks. In this method, a random start/end point for each edge of the irregular part is chosen. The problem now reduces to a standard Travelling Salesman Problem, which is solved to get a solution. The start/end points of the cells are now changed and the computation is carried out all over again. While this iterative procedure is easier to implement because it deals only with standard travelling salesman problems. The optimal cutting sequence in laser cutting can be formulated as a special case of the TSP; it is one of the combinatorial optimization problems. In such formulations, each ends of the edges to be laser cut are represented as points to be visited during the tour and the cutting sequence should satisfy the following condition: the cut should start at one end of the edge and end at the other end of the same edge.

The discussions reveals: optimal cutting path would be different for different layouts. Minimum production cycle time can be obtained by changing the layout. Optimization of one objective would lead to sub optimal solution for the other objective. On these considerations this paper proposes a methodology to evolve

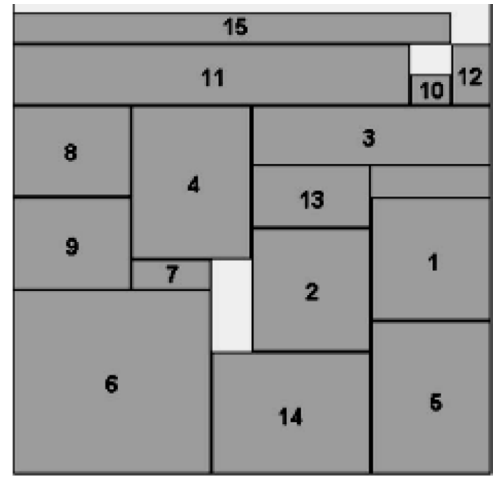

Fig. 1. Nesting layout of regular shaped parts in regular sheets.
Source: [11].

optimal cutting path for different layout options. This approach provides an initiative to consider simultaneously both the critical objectives of sheet metal cutting industries. With different layout options and their corresponding optimal cutting plans, both the objectives could be simultaneously addressed and the compromised solution could be obtained through multi-objective optimization techniques. However, this paper focuses on the development of a solution technique for optimal cutting plan to any given layout. Ever since Kirkpatrick introduced the concept of annealing into the Travelling Salesman Problem (TSP) in 1983, interest in the simulated annealing technique of obtaining approximation solutions for problems with combinatorial optimization has grown rapidly [5]. On this consideration, simulated annealing algorithm (SAA) is considered to evolve the optimal cutting path. The proposed solution technique 'SAA' is illustrated with the optimal material utilization layout obtained using sheet cutting suite software, a professional rectangular nesting software package and optimal cutting path evolved through SAA. The rest of the paper is organized as: Section 2 presents the survey of literature; Section 3 describes the problem; Section 4 illustrates the proposed sequential optimization approach; discussions on the proposed approach is dealt in Section 5; the conclusions summarizing the scope of the present work, its limitations, and the future research directions to enhance the applicability of the proposed approach are discussed in Section 6.

2. Literature review

This section presents the survey of literature that has been studied extensively for the productivity related issues in laser cutting on the categorisation of the following four types of problems:

Problem type I : Nesting of regular shaped parts in regular sheets (Fig. 1)
Problem type II : Nesting of irregular parts in regular sheets (Fig. 2)
Problem type III : Nesting of irregular parts in irregularly shaped sheets (Fig. 3)
Problem type IV : Optimal path planning with minimum path length (Fig. 4)

2.1. Nesting of regular shaped parts in regular sheets

Israni and Sanders [8] considered the allocation of regular shapes onto stock sheets in a manner that minimizes the trim losses. The costs of inventory and production have to be included in the objective to be minimized in order to ensure maximum production efficiency. An algorithm based on the first fit decreasing heuristic is presented to achieve layouts of rectangular bill of material on rectangular stock sheets, and its performance is examined. Lai and Chan [9] presented a simulated annealing based searching