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Methodology to optimize dead yarn and tufting time for a high performance CNC by heuristic and genetic approach

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ABSTRACT

To achieve a high productive manufacturing ability and reduce dead yarn accumulation, a novel computer numerical control (CNC) machine and an efficient methodology was proposed to generate optimal or near optimal sequences of tool paths for minimizing manufacturing time. Two methods are available to generate complicated and customized photo-based carpets: to fit pre-drawn curves on a fabric backing by using a portable tufting gun and to generate available tool paths from a computer-aided manufacturing (CAM) system for a robotic tufting gun. These two operations are not suitable for high-speed applications. The solution proposed in this study starts from the original needle location paths provided by computer graphic software to solve a traversing tuft problem (TTP). The obstacle of the innovative manufacturing process, in reducing the time of the travel path for the tufting of the CNC machine, was solved. The methodology can be easily implemented using a CAM system. Several industrial experiments were proposed, which demonstrate substantial improvements of the proposed algorithm over solutions provided by application software. Moreover, for optimizing the usage of yarn in a spindle traverse movement, we present a high-performance implementation a heuristic genetic algorithm (GA) that allows achieving the optimization task efficiently. A graphical user interface that integrates the entire process was presented.

1. Introduction

The knowledge of the difference between custom manufacturing and mass production considerably influences two factors: the manufacturing process of products and production cost. The customized patterns can be regarded as favorite collections. Moreover, manufacturing companies must consider the aforementioned two factors. With increasing demand for complex graphics and digital images in various applications, such as carpets, rugs, mats, and pads, textile manufacturers are exploring effective solutions to produce textiles with higher productivity, lower manufacturing costs, and particularly less material wastage. Carpets are soft, slip-resistant, and quite beautiful. Therefore, carpets are prevalently used as a floor covering for specified spaces. With increasing environmental awareness, responsible manufacturers are continually pressured to develop sustainable practices related to their products. In this study, cost-effective and environmentally friendly options were implemented, which were tailored to customized requirements of complex carpet patterns.

Machine-made carpets have relatively satisfactory finishes and very smooth surfaces. In conventional carpet mass production, machines insert yarns into primary backing and can produce patterns and textures; the machines can vary pile heights, positions of yarn in needles, and whether the yarn is loop pile or cut pile. For a 2-m wide carpet with a 5-mm needle spacing, 400 needles are equipped in a row on the tufting machine for a single-color pattern, and 2400 needles can produce six-color patterns. Manufacturing customized carpets by using the current modern technologies is difficult because of long lead times and high costs.

Most modern manufacturing companies are driven by rapid technological advancements. A short lead time is strongly required. Tufting is prevalently used for machine-made carpets. In the machines used for tufted carpets, yarn is stitched through pre-constructed backing to form a loop or tuft. Tufting is the most inexpensive and rapid method for carpet manufacturing. A carpet manufacturing process includes manufacturing methods for various types of carpets. Environmental and health concerns associated with carpet manufacturing include indoor air quality, toxic chemical emissions from manufacturing and disposal operations, and solid waste problems. To manufacture dimensionally stable tufted carpets, two layers of backing are frequently applied to the carpet. Backing present directly beneath the pile yarn is termed primary

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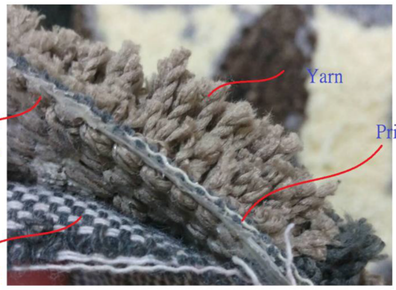

Fig. 1. Illustration of carpet construction.

backing. Fig. 1 shows secondary backing that is attached to primary backing by a layer of rubber or latex.

The productivity of machine tools can be considerably improved using graphical computer-aided design/computer-aided manufacturing (CAD)/CAM systems for computer numerical control (CNC) program generation. CAD/CAM packages provide embedded postprocessors to generate appropriate numerical control (NC) codes for various machining processes, one of which is a point-to-point (PTP) drilling operation. Like the traveling salesman problem (TSP) [1–3] stated in a remarkably way that given a list of cities and the distances separating them, the shortest possible route that visits each city exactly once is the most concerned. Nowadays it supports many practical applications in areas as optimizing routes of the drill machine used to drill holes in a printed circuit board or minimizing material wasted in the cutting stock problem. A significant comparison of metaheuristics used for TSP could be found in [4], which discusses genetic algorithms, simulated annealing, tabu search [5], quantum annealing, particle swarm optimization [6,7], harmony search, and ant colony optimization [8,9]. Many works have been reported for minimizing the productive time by optimizing the machining parameters [10,11], type of tool paths to be included [12], tool selection and tool sequencing [13], nevertheless, very limited number of works have considered non-productive tours. A minimum path search algorithm using GA was developed by Gupta et al. [14] for the tool-path optimization. The algorithm successfully optimized the number of retraction points together with total traversing time. Ho and Ji [15] proposed a hybrid genetic algorithm to optimize the sequence of component placements on a printed circuit board. Li et al. [16] examined two-tool parallel drilling process plan optimization problem using two phase GA. Firstly, the GA is used to determine the optimal process parameters satisfying all constraints such as drill feed, spindle speed, thrust fore, torque, power and tool life, and the minimum machining time is the optimization criteria. Secondly, the GA is used to determine the operation completion time and machining sequence. The minimum operation completion time is the optimization criteria in this phase. A recent work used a hybrid cuckoo search-genetic algorithm for hole-making sequence optimization could be found in [17]. The non-productive time consumes a lot of total machining time and varies with complexity of the job that for the machining of multi pocket jobs by small diameter tool [18]. Therefore minimization of non-productive time becomes important in case of multi pockets jobs [19]. To find the best sequence and orientation of productive tours required for producing superior tufted patterns corresponding to heuristic methods, genetic strings are formulated with sequence of tours and their orientations. Then, through several genetic operations such as initial population, reproduction, crossover and mutation, the best strings that score the highest fitness value are evolved. From the literature, the genetic algorithm for minimizing traveling distance is discussed in terms of a pair of parents generating a pair of children [20–24]. More recently, there has been an increased interest in enhancing task scheduling for industrial robots based on TSP and GA [25–27]. Remodeling TSP to robotics, the measure to be optimized is total time instead of total distance.

Machine tufting can be used to manufacture several types of carpets. Tufting machines generally use a row of several hundred needles to simultaneously insert tufts into each row of the backing fabric. The movement is performed continuously along a given direction to form a basic uniform pile. The piles creating the basic pattern of the carpet along the direction can be in the form of cut pile, loop pile, cut-loop pile, and level-cut-loop pile. Pattern design elements of a basic carpet pattern are repeated along the direction. Therefore, the present tufting machines for manufacturing carpets are generally limited to producing a basic pattern along the direction, which limits the designs that can be produced using the available carpet manufacturing processes and equipment.

The remainder of this paper is organized as follows: Section 2 presents the tuft optimization problem, which focuses on the optimization of the traversing paths of tufting tours and is considered analogous to the TSP. Section 3 introduces the methods for generating paths and presents general operational principles with parameter functions. The mathematical foundation of a TTP is presented. Section 4 provides heuristic and GA implementation details of the proposed methodology. In Section 5, the conducted experiments and results are illustrated to validate the feasibility of the proposed method, and the graphical user interface of this development is also presented. Finally, Section 6 presents the conclusions of this study.

2. Traversing tufting problem representation

Dead yarn is a pile yarn in a carpet that is concealed in the backing structure, which does not form a pile tuft. Since the tufting paths are implemented on the back of the primary backing, the minimization of the dead yarn is a priority in this study. In the well-known TSP, a salesman starts from his hometown, figures out how to find a shortest route that takes him through a given set of customer cities, and visits each customer city exactly once. The simplest Traversing Tuft Problem, all single tufting nodes, can be regarded as similar to the TSP, but with a spindle instead of a salesman. The TSP is used in several applications, such as the optimized scheduling of CNC machine routes for drilling holes in a printed circuit board or maximizing material usage in a cutting stock problem. Tufting positions can be considered as cities, indicated by red spots in Fig. 2(a). The decision TSP problem is a typical NP-hard problem [28] but there remains the issue of whether one can quickly find an excellent approximation to the TSP.

If the first node is fixed, the number of probable routes for a graph with n nodes is $(n-1)!$. The total distance is the same regardless of whether the graph is heading forward or backward. The number of probable distinct solutions is $(n-1)!/2$. Although the problem statement is simple, solving the TSP is difficult because it is an NP-complete problem. Moreover, the TTP is more complicated than the TSP because the city is large. A city may comprise several towns, and thus, the system must determine the towns to be assigned to each city and the superior sequence of the cities for each trip. Not only the tuft nodes are grouped to form productive tours, but also apply connective allowance and orientation to this problem, which cause higher complexity in computing the solution. There are three operators that engage the operation of the proposed method:

Strong-productive tour path: a series of nodes (piles) linked together side by side;

Weak-productive tour path: a series of strong-productive tours linked