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Optimized sequencing of CNC milling toolpath segments using metaheuristic algorithms †

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Abstract

Intelligent selection of a short toolpath is made possible by reducing machining cycle time. Each metal cutting layer in a workpiece is composed of several entities, such as lines and arcs, which form the different cutting segments of a cutting plan. During machining, the cutter moves at controlled feed rates along various segments at a high speed in a single cutting pass. The end of a segment is bridged to the start point of the next segment by the non-cutting movement of the tool. Any two consecutive segments can be connected in eight different ways. Finding the shortest tool path at polynomial time is impossible because toolpaths are constructed in millions of ways by sequencing the segments. This paper presents an effective method that uses heuristic optimization techniques to solve this NP-hard problem, which is known as the traveling salesman problem, for segments. The proposed method adopts particle swarm optimization (PSO) and the genetic algorithm (GA) because of their capability to generate quality solutions for optimization problems. GA and PSO are implemented in the MATLABR2016b computing environment because of the platform's flexibility and simple coding method. The optimization procedure is validated by comparing its results with those of two industry standard CAM systems, namely, Autodesk Inventor HSM and Mastercam. Using the proposed optimization method saves up to 40 % of the tool's airtime during machining.

Keywords: CAM; CNC milling; Genetic algorithm; Metaheuristics; Particle swarm optimization; Toolpath optimization; Traveling salesman problem

1. Introduction

Milling is a versatile machining process commonly used to manufacture industrial products with various shapes and sizes. Rotary cutters remove a material through several small, separate cuts from a workpiece by feeding the workpiece to a path. The workpiece dimensions are defined using a computer-aided design program and transformed into machining commands by a computer-aided manufacturing system. When metal removal is performed with a typical toolpath, a large amount of unproductive time is spent on positioning the workpiece between the ends of one segment of the path to the starting coordinate of the subsequent segment. The non-cutting movement of the tool in air follows a straight line in many operations. Non-machining time can be minimized through efficient toolpath selection. Cycle time is the sum of tool engagement time, the time the tool is away from the workpiece, and the time required for other activities, such as tool changes and inspection. This non-engagement time increases with the number of segments planned and multiplies further with the number of passes for a required cutting depth to complete metal removal. With an increase in production volume, this non-productive time becomes considerable in the overall manufacturing time of the product. The standard procedure of creating toolpaths involves the use of CAM software, which has built-in functions to optimize the cycle time to a certain extent. Toolpaths must be optimized with intelligent techniques to achieve efficiency and increased productivity in a large product mix business.

In contour milling, the tool plunges into the workpiece at one end of the arc and leaves for the next segment after performing the cut. Kovacic and Balic [1] developed a method for optimized toolpath between cutting trajectories in a laser-cutting operation. They reported that the tool for a toolpath with a single segment could begin from either end. Thus, selecting between these two paths is an option. A 10-segment cutting plan has 3.71 billion possible routes. The possible number of toolpaths for a given number of "n" trajectories is $2^n n!$ (for bidirectional edges). Table 1 shows the complexity of selecting a toolpath. Determining the best solution via traditional calculation is difficult, even for a simple toolpath program with 10 segments. The best solution obtained after exhaustive calculation becomes minimally effective because of the considerable time spent, and this necessitates the use of heuristic approaches to determine the solution within a short

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