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CNC MACHINING OPTIMIZATION BY GENETIC ALGORITHMS USING CAD BASED SYSTEM

Gabriel Mansour[1], Apostolos Tsagaris[2] & Dimitrios Sagris[3]

[1] Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki, Greece,
[2] Department of Automation, Technological Educational Institution of Thessaloniki, Greece,
[3] Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki, Greece,

Corresponding author: Gabriel Mansour, mansour@eng.auth.gr

Abstract: This paper proposes an expert CNC system, which optimizes the machining path process by deciding the optimum path. Based on CAD program is a kind of integration and it is designed to control a CNC machine. Graphic features and geometric parameters are extracted from CAD part drawing and performed to control the machine motion to cut the part. Genetic algorithms are used in order to optimize the path at the shortest time. The CNC system is able to optimize paths autonomously between cutting trajectories, determined by the product's CAD model. The efficiency of CNC machining is improved greatly and the cutting time is reduced. The proposed system, including several function modules, is developed under Visual C++ environment.
Key words: Genetic Algorithms, optimization, system integration, CNC machining.

1. INTRODUCTION

CNC system are consisting of mechanical feed drives, motors, amplifiers, position-velocity-acceleration sensors and real-time computer algorithms which generate time stamped position commands through trajectory generation and close the axis servo loops (Altintas, 2000). Devices. Since the 1950s, Computer Numerical Control (CNC), have gone through several generations, following the state-of-the-art computational platforms. Today the G-code programs are generated by the Computer Aided Manufacturing (CAM) tools, using the geometrical data from Computer Aided Design (CAD) tools as input. In order to generate G-code programs for different CNCs, CAM tools need to know not only the particular brand and model of a CNC, but also need to have a detailed description of the machine tool, the code structure and their peripherals such as cutting tools and other auxiliary components. This information is being handled by a special unit within a CAM tool called ‘‘post-processor’’ which operates with full knowledge of G-code, machine-tool and details of cutting tools. (Fig. 1)

CNC path optimization is a typical optimization problem. The goal is to minimize the time for the movements of the tool during the cutting process. Many researchers use a variety of algorithms to solve this problem, such as simulated genetic algorithm (Carter & Ragsdale, 2006), annealing algorithm (Meer, 2007), ant-colony algorithm (Dorigo & Gambardella, 1997, Dorigo, 2000) and neural network algorithm (Ghaziri & Osman, 2003). Tandon et al. are using an artificial neural networks (ANN) predictive model for critical process parameters to predict the cutting forces which in turn are used by the particle swarm optimization (PSO) developed algorithm to optimize the cutting conditions subject to a comprehensive set of constraints (Tandon et al., 2002). The algorithm is used to optimize both feed and speed for a typical case found in industry, namely, pocket-milling. Machining time reductions of up to 19% are observed. In addition, the new technique is found to be efficient and robust.

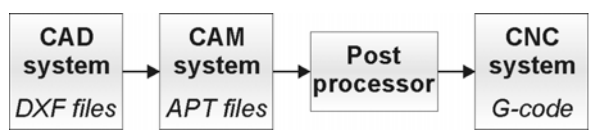

Fig. 1. CAD/CAM and CNC Integration

In the last years, the technology of automatic programming is developed rapidly. The use of genetic algorithms (GA) (Holland, 1992) based approach for programming of CNC turning and milling machine tools is increasing rapidly. Genetic algorithms strongly differ in conception from other search methods, including traditional optimization methods and other stochastic search methods. The basic difference is that while other methods always process single points in the search space, genetic algorithms maintain a population of potential solutions.

Omirou and Barouni proposed a series of machine codes selected for integrating advanced programming capabilities into the control of a modern CNC milling system (Omirou & Barouni, 2005). The researches describe how the new functions are properly integrated into a CNC milling system. Pengfei et al. described an intelligent CNC system software based on a VB application, which applied the ant-colony algorithm to auto-optimize the cutting tool paths in machining process (Pengfei et al., 2010). Kovacic and Brenzocnik proposed a concept based on genetic algorithms that assures evolutionary generation and optimization of NC programs on the basis of CAD models of manufacturing environment (Kovacic & Brezocnik, 2005). This concept can be adopted also to other machines for example coordinate measuring machines (Mansour et al., 2005), welding machines, laser and plasma cutting machines (Kovacic & Balic, 2002), robots and manipulators (Mitsi et al., 2008). Balic and Korosec shown how with the help of artificial neural network (ANN) (Balic & Korosec, 2002), the prediction of milling tool-path strategy could be made in order to establish which milling path strategy or their sequence will show the best results for free surface machining.

Chiou and Lee present a machining potential field method, which is constructed by considering both the part geometry and the cutter geometry, to generate tool paths for multi-axis sculptured surface machining (Chiou & Lee, 2002). The tool paths can be generated by following the optimal cutting direction.

This technique can be used to automate the multi-axis tool path generation and to improve the machining efficiency. Nemoto et al. describe a method for generating NC part-programs in which a special device saves the data about parts, associated coordinates, characteristic junctions and assembly times for single electronic components (Nemoto et al., 1999). The solution enables shortening of the time for the composition of NC programs and reduction of mistakes in preparing of programs.

The goal of the present paper is the development and incorporation of tool path generators into CNC systems, based on efficient and accurate tracing methods, capable to satisfy the increasing industrial demand for machining complex shape parts. The important is that the system is totally integrated to work directly with DXF file formats, which is a common format for all the CAD softwares.

2. THE SYSTEM

The application consists of a user friendly Human Machine Interface (HMI). The designed feature of the parts are identified and extracted from CAD drawing to control the parts with automatic machining by the intelligent CNC system software. From the CAD system the features are extracted thought the Data Exchange Format (DXF). The PC software programmed under Visual C++ environment is developed to identify and extract the machining feature, calculate the parameters, manage data, schedule tasks and interact between human–computer on Windows platform. The data are imported from the CAD system as DXF file. At the same time a simulation process is running and shows the drawing in a special window. The next step is to calculate the optimum path. Finally the extraction of the G-code in a file takes place, ready to use for the CNC machining. A diagram of the software function modules is shown in Fig. 2.

The software interface of the CNC system shown in Fig. 3 includes menu, toolbar, graphical display area, buttons, list-boxes and textboxes. The left list box is showing the DXF file as text file. The graphical display area is showing the DXF drawing. The three textboxes are used for the coordinate values of X, Y and Z.

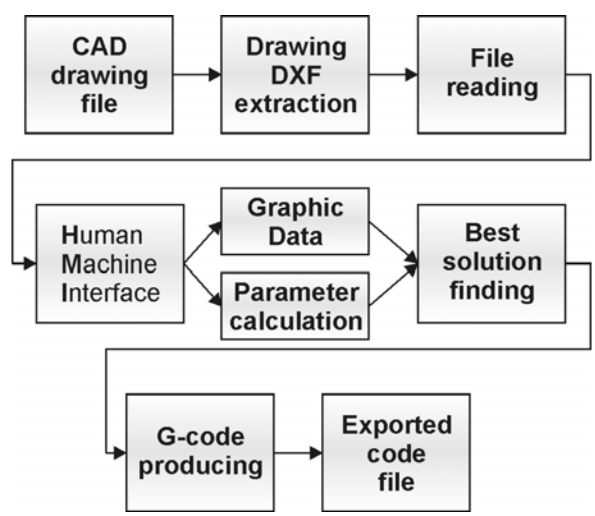

Fig. 2. Architecture of system

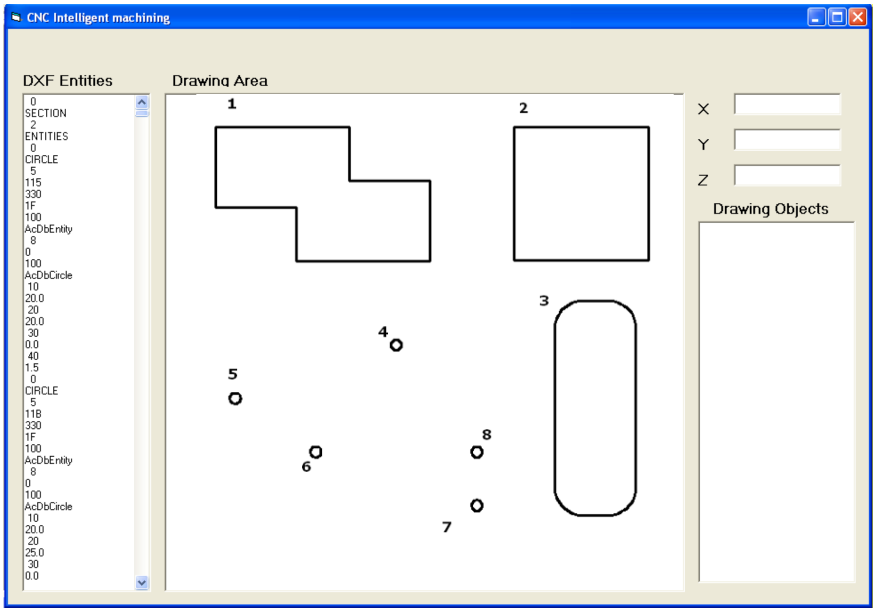

Fig. 3. Software Application

The identification and extraction of part machining feature from CAD drawing is the most important work for PC software. The structure of DXF file is analyzed and the geometric data of CAD drawing are stored in the ENTITIES section of DXF file. The ENTITIES section of DXF file is giving the necessary information for the drawing objects. By reading the contents of ENTITIES section in the programming procedure, the machining feature parameters of parts are identified, extracted from CAD drawing and stored in the appropriate list box (right list box).

The explanation of the entities section is illustrated in Fig. 4. Firstly, the contents of DXF drawing are read and followed by the line until ENTITIES section. Secondly, after the group values of ENTITIES section are read, the different graph features are identified according to the group value. The parameters of graph feature are extracted by the corresponding function software according to the classification [9]. In the list box "Drawing object" are included all the identified features from the CAD file with all the necessary geometrical information. These features are presented in the drawing area in the middle of the software. To extract the feature from the DXF file, a parametric file is used with all the information for each feature such the name, the start and end point, the radius, etc. This parametric file allows adding new features and the software became a parametric aspect.

Genetic Algorithm used to optimize the CNC path. It is proved that the genetic algorithm has the obvious superiority in solving the combinatorial optimization problems. The main advantage of a GA is the flexibility to adopt itself to continuously changing optimization criteria and constraints.

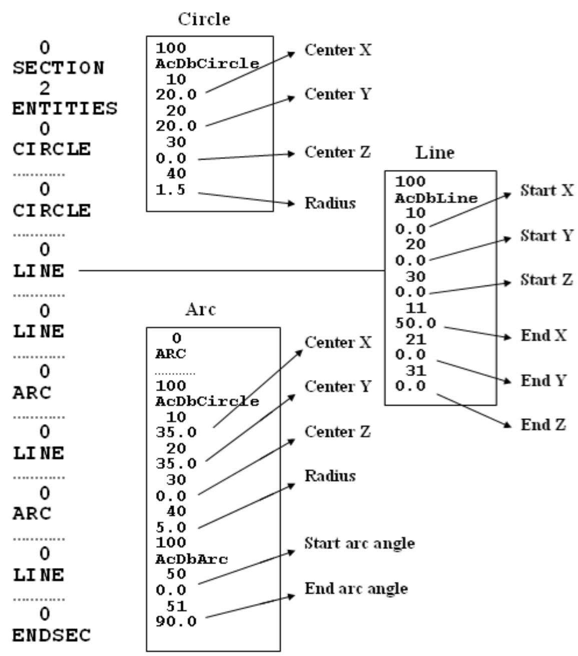

Fig 4. DXF file description

Factors such as representation of individuals, decoding methods, initial population, the selection scheme and the choice of genetic operators, have a great deal of influence on the performance of the genetic algorithm itself (Tiwari et al., 1997). The objective is to define the terminologies and to discuss the various design issues (e.g. representation, initialization, evaluation function, crossover, mutation, and elitist strategies etc) related to a genetic algorithm with reference to its application in solving the problem (Gen & Cheng, 1997).

3. IMPLEMENTATION AND EXPERIMENTS

The main aim is to reduce the production time. Initially the travel distance has to be calculated and after that depending on the cutting and feeding speeds the necessary time for the sequence is estimated. The NC program is created at random based on the sequence in which the features on the drawing are extracted. The points on the features are created depending on their characteristics and are coming directly from the DXF file. They are cutting motions and feeding motions which are the connections between the points. Each feature is coded with a number.

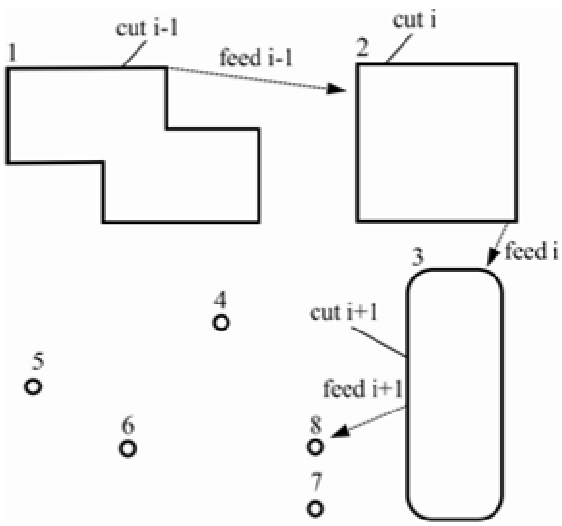

Fig. 5. Cutting and feeding motions

The evolutionary-supported problem is to obtain an optimal cutting path between determined cutting features. Each object will be coded and the genetic algorithm will choose the appropriate sequence for the cuttings that the overall required time is the shortest possible.
The steps executed in the algorithm are the following:

Step 0. Once the data are encoded, the length of the chromosome is defined using k digits (representing the number of slots that the objects will be placed). For example, chromosome [2 3 1 5 4 7 6 8] means that the set of seven objects that have been previously extracted will be cut with the above sequence.

Step 1. The initial population is generated, based on the assumption that the size of the population is 10 and the maximum number of the generations is 50. The crossover probability was 0.5 and mutation probability was 0.3.

Step 2. The fitness value of each member of the initial population is calculated. The fitness function (F) value is used to minimize the total time needed to cut all the objects.

$$F = \sum_{i=1}^{n-1} tc_{i,i+1} + \sum_{i=1}^{n} tf_i$$

where:

$tc_{i,i+1}$ = time of cutting motion between cuts i and i+1

tf_i = time of feeding motion i

Step 3. The output of the fitness value in each chromosome is stored in a temporary table.

Step 4. The two best ones are selected.

Step 5. A crossover is applied between the two chromosomes of step 4. In addition, mutation and inversion are applied on each one separately.

Step 6. The new six chromosomes created are added to the four best ones from Step 3 in order to complete the population of 10.

Step 7. Simultaneously, the best value from Step 4 is temporarily stored.

Step 8. The fitness value of each member of the initial population is calculated and the steps 3 to 6 are repeated.

Step 9. If a better value is acquired, then it replaces an old one.

Step 10. The process is repeated 50 times and the best solution is achieved (the sequence of the object cut in the least possible time).

The GUI (Graphical User Interface) of the software used to execute the genetic algorithm is depicted in figure 5. The different actions of the genetic operations are presented (crossover and mutation). At the upper text fields (cyan color), the user can select the file pathnames for the initial data and the results. At the right hand side (dark grey area), the GA parameters used are presented on top of the final solution achieved (blue area).

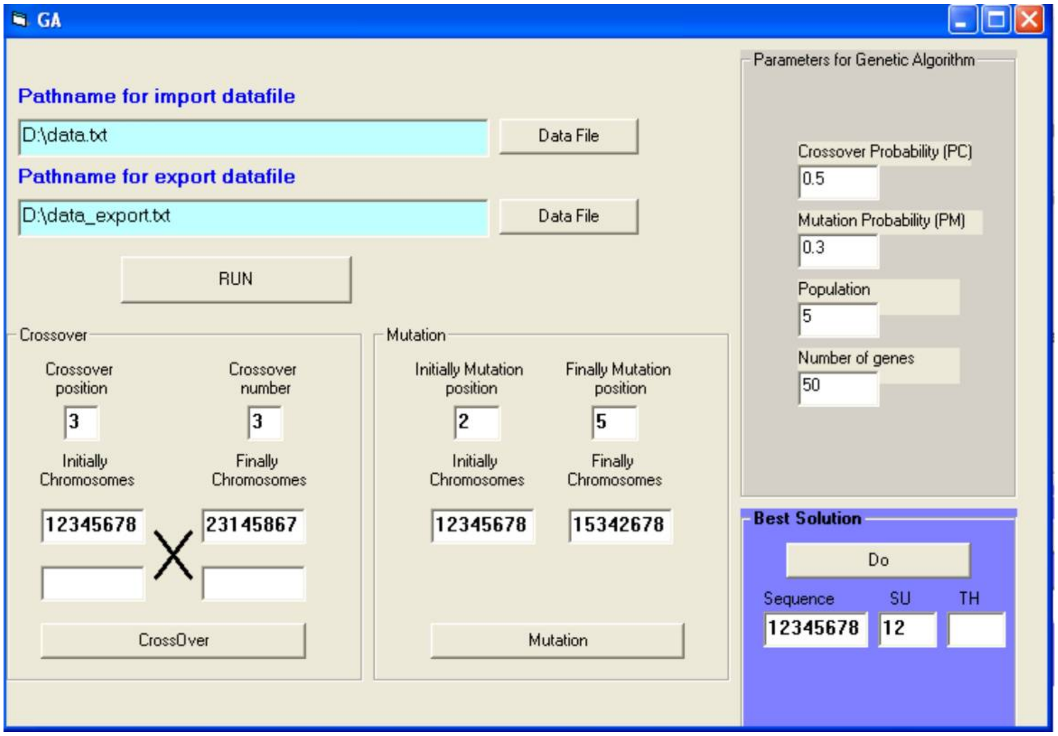

Fig. 5. Genetic Algorithm software Interface

4. RESULTS

The cutting motion is the same in both cases. The optimization is done on the feeding motion. The comparison of the random cutting selection (Fig. 6) and optimal cutting solution (Fig. 7) gives a time difference of 18.63%. It is important that the difference between the two strategies in Figs. 6 and 7 is not obvious. The evolutionary-programmed machine tool has to establish autonomously a hidden optimal solution. Figure 7 shows an optimal solution, i.e. an optimal cutting strategy. The numbers from 1 to 8 represent the cutting sequence. A random cutting strategy length is 644.88 units. The optimal cutting strategy length is only 524.78 making the difference 18.63%.

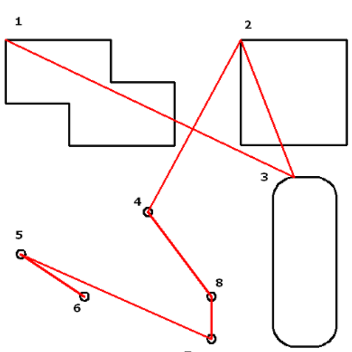

Fig. 6. Random cutting Selection

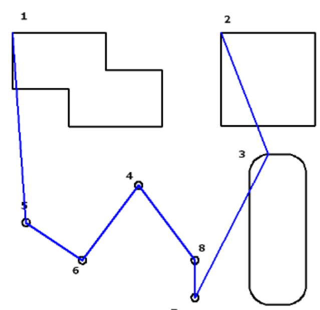

Fig. 7. Optimal cutting solution using Genetic Algorithm

5. CONCLUSION

The present paper proposes an expert CNC system, which optimizes the machining path process by deciding the optimum path. The main components of this system are the integration of CAD program and CNC machine and the optimization method, which is based on genetic algorithm. In the proposed system the final part comprise internal and external cuts. The cuts are of any shape; they consist of lines, arcs and circles. The proposed intelligent system is capable to handle automatically the futures of the parts in the layout, to determine the sequences of cuts forming the laid out part. By the genetic algorithm method the system is capable to find the shortest path between individual cuts and to record the NC program. With minor corrections, adapted to the user, the system can be quite practically used.

The evolutionary method GA, which has been proved to be an effective optimization tool, was successfully implemented for autonomous CNC cutting programming. CNC programming represents 25% of the production time. The programming phase, i.e. the manufacturing planning and optimizing phase, was successfully fully automated. The proposed concept of the production system uses biological evolution principles of genetic combinations and natural selection of the fittest. The proposed concept is a contribution to the intelligent manufacturing systems of the future.

Future work will consider on more complex parts with more constraints.

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