Research Journal of Applied Sciences, Engineering and Technology 8(6): 746-754, 2014
DOI:10.19026/rjaset.8.1030
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: May 19, 2014 Accepted: June 16, 2014 Published: August 15, 2014

Research Article

Application of Artificial Intelligence Methods of Tool Path Optimization in CNC Machines: A Review

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Abstract: Today, in most of metal machining process, Computer Numerical Control (CNC) machine tools have been very popular due to their efficiencies and repeatability to achieve high accuracy positioning. One of the factors that govern the productivity is the tool path travel during cutting a work piece. It has been proved that determination of optimal cutting parameters can enhance the machining results to reach high efficiency and minimum the machining cost. In various publication and articles, scientist and researchers adapted several Artificial Intelligence (AI) methods or hybrid method for tool path optimization such as Genetic Algorithms (GA), Artificial Neural Network (ANN), Artificial Immune Systems (AIS), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). This study presents a review of researches in tool path optimization with different types of AI methods that show the capability of using different types of optimization methods in CNC machining process.

Keywords: Artificial intelligence, CNC machines, machining, optimization, tool path

INTRODUCTION

Recently, the advanced of computer system and improvement of semiconductors in various field have lead to the enhancement of machining process especially that involved Computer Numerical Control (CNC) (Li and Frank, 2006). The CNC machining are used mainly in manufacturing areas such as machining parts for automotive tools, jig and mold. The main advantage of CNC machining is catch high machining accuracy with easily programming and repeatability in complicated parts machining (Al-Kindi and Zughaer, 2012; Safaieh *et al*., 2013).

The conventional ways of selecting the tool path or programming the NC code used data from machining handbooks and the knowledge of programmer for optimal processing (El-Midany *et al*., 2006; Suh and Lee, 1998). However, the conventional or traditional NC programming when compared to the modern CNC machining has many disadvantages for instance increasing time and cost production and, decreasing accuracy and quality of the workpiece (Liu *et al*., 2013; Lasemi *et al*., 2010).

Nowadays, most of the CNC machines tools are programmed automatically using Computer Aided Manufacturing (CAM) software instead of manual program input in order to reduce programming time and to avoid human errors (Mattson and Mattson, 2009; Suneel and Pande, 2000). Therefore, one of the most essential factors in optimizing the machining process is the selection of tool path.

For example, before a machinist performs an optimal cutting process using CNC machine tools, the tool path for tool processing should be determined before the actual tool processing (Zhang *et al*., 2011; Mayor and Sodemann, 2008). In general, the current way of tool path selection is based on the set of ordinary path such as zig, zig-zag, radial, spiral tool paths etc (López de Lacalle *et al*., 2007).

The objective of this study is to review of prior works on tool path optimization in CNC machines in order to classify different types of machining process with CNC machine tools. First we describe an overview of optimization methods. In the next section, collection of all previous research in tool path with different types of Artificial Intelligence (AI) optimization methods will be presented to show the ability of various methods in optimizing machining process.

DIFFERENT AI OPTIMIZATION METHOD

Different types of optimization methods in AI have been adapted in many previous researches to find optimum parameters for machining process. In general, AI is a branch of Computer Science (CS) which are developed and emerged in the mid-1950s that deals with the intelligence of machines (Jones, 2008; El-Mounayri *et al*., 2002). Since then, it had generated numbers of

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powerful tools that have practical usage especially in engineering in order to solve difficult problems which normally need the secrets of Natural Intelligence (NI). The research in AI is designed for the simulation of NI by making the machines to be intelligent (Zhong, 2008). In the next section we will describe separately of each AI methods used in tool path optimization.

Genetic algorithms: A Genetic Algorithm (GA) adapts the manipulation of a population of potential solutions for optimize problem (Agrawal *et al*., 2006; Chan *et al*., 2005). In 1970s, Holland (1992) first proposed the genetic algorithms, GA stand the one of the interesting investigation method in search algorithms (Man *et al*., 1996). GA has three main operators, crossover, reproduction and mutation. GA method use binary encoded way to coding the process parameters in optimization of machining process. In this method important section is choose appropriate parameters and constraints for the algorithms to perform efficiently. Until today, the GA has been successfully applied for optimization problem in various fields. For instance, the problem formulation that used Travel Salesman Problem (TSP) can be solved by GA. TSP is a Non-deterministic Polynomial time (NP) -hard problem and one of the most widely studied combinatorial optimization problems (Langevin *et al*., 1990; Laporte, 1992). It is based on the task to find the shortest possible route for any number of cities and the costs of travelling from any city to any other city (Qudeiri *et al*., 2006).

Artificial neural network: ANN is a computational model inspired from natural neurons concept. Since the first neural model by McCulloch and Pitts (1943), there have been developed hundreds of diverse models considered as ANNs (McCulloch and Pitts, 1943; Karayel, 2009). Different types of ANN such as feed forward, radial basis function and Kohonen self-organizing neural networks are used to model real neural networks to study the behavior and control in animals and machines (Bose and Liang, 1996; Ghosh *et al*., 2007). Nowadays, there also are ANNs that are used for engineering purposes, for example pattern recognition, forecasting and data compression (Ghosh *et al*., 2007; Bose and Liang, 1996; El-Mounayri *et al*., 2005; Yang and Zhuang, 2010).

Artificial immune systems: AIS are intelligence and adaptive systems inspired by observed immune function, principle and models, which are applied to toward real-world problem solving (Ülker *et al*., 2009; De Castro and Timmis, 2002). Two generations of AIS are currently in use, with the first generation relying on simplified immune models and the second generation applying interdisciplinary collaboration to develop of the immune system and hence produce more complex models (Li *et al*., 2011). In variety of problem can applied both generation of algorithms, including anomaly detection, dependable systems, pattern recognition, optimization and robotics (Wang *et al*., 2011).

Ant colony optimization: The ACO is consequences of research based on computational intelligence approaches used for solving combinatorial optimization problems. ACO is stimulated by the foraging behavior of ants and their natural aptitude to find the shortest path from a food source to their nest (Dorigo and Blum, 2005; Blum, 2005; Dorigo *et al*., 1996; Chandra Mohan and Baskaran, 2012). This characteristic of real ant colonies is exploited in ACO algorithms in recent techniques for approximate optimization. However, ACO one of the youngest meta-heuristics techniques. The number of ACO applications is covered large area such as industrial, multi-objective and bioinformatics problems (Kanan and Faez, 2008; Yang and Zhuang, 2010).

Particle swarm optimization: PSO is an optimization technique based on the behavior of a swarm of insects such as ants, bees or a flock of birds which is originally proposed by Kennedy and Eberhart (1995). In PSO, each potential solution is assigned a randomized rapidity called particles which are flown through hyperspace (Shi *et al*., 2007). PSO is evolutionary technique similar to GA because both are population based and are equally affective. Many studies have successfully employed PSO and its variants to optimize process parameters of several manufacturing processes such as drilling, welding and turning (Eberhart and Kennedy, 1995; Kanan and Faez, 2008; Kennedy and Eberhart, 1995).

LITERATURE REVIEW ON TOOL PATH OPTIMIZATION

There are quite numbers of literature related to tool path optimization by AI can be found. Most of them used GA, ANN, ACO, AIS and PSO optimization methods. For instance, Chen and Tseng (1996) proposed of using GA for planning of a near-optimum tool path and location of a workpiece. They tried to reduce the processing time required for a robot to complete its work on a workpiece (Chen and Tseng, 1996). In addition, Dereli *et al*. (2001) used GA to determine the optimal cutting parameters for increasing productivity and competitiveness.

Castelino *et al.* (2003) presented an algorithm for minimizing the airtime for milling process by optimal connected diverse tool path divisions. They combined the TSP and Sequential Ordering Problem (SOP) for formulation as a generalized with precedence constraints. This algorithm used in an automated process planning system, also can be applied to other parts of path planning optimization (Castelino *et al*., 2003). Moreover Cus and Balic (2003) proposes a new approaches on GA for solving the optimization problem is both effective and efficient of the cutting parameters in machining operations. Finally this proposed approach will lead to reduction in production cost, production time and improvement of production quality (Cus and Balic, 2003).

For free form surface or sculptured surfaces, Agrawal *et al*. (2006) presented the minimization of machining time while implementing Iso-scallop machining. The positioning of the primary Master Cutter Path (MCP) was achieved through application of GA.

Qudeiri *et al*. (2006) attempted to find an efficient solution approach to determine the best sequence of operations for a set of holes that are located in disproportionate locations and diverse levels. Oysu and Bingul (2007) proposed of using GA for different processing techniques in tool path optimization in order to minimize the unproductive air during machining. They adapted GA with pre and post-processing techniques to reduce the tool paths for optimize airtime travel on three axis Cartesian routers during milling of wood materials. Their results show that GA with pre and post-processing techniques gave shorter computation time 33.7% which was better path solution rather than standard GA. Their study focused on finding the shortest Cutting Tool Travel Path (CTTP) for Hole-Cutting Operations (HCO) with GA and formulated CTTP as a special case of the TSP (Oysu and Bingul, 2007). Also Queiri *et al.* for find the best sequence of operations to achieves the shortest CTTP used GA (Qudeiri *et al*., 2007).

In milling machining Palanisamy *et al.* (2007) used GA optimization technique for find the optimal process parameters. The obtained results indicated that the optimized parameters are capable to reach more efficiently result (Palanisamy *et al*., 2007). Also Saravanan and Janakirman (2007) used GA for find minimum machining time by optimizing machining parameters such as cutting speed, tool path and feed rate. Moreover for increase production rate and reduce production cost Durán *et al*. (2007) proposed Non-dominated Sorting GA (NSGA).

In the process parameters optimization of tangential turn-milling machining Savas and Ozay (2008) used GA method. In the result for surface roughness optimization, investigate on diverse process parameters such as depth of cut, workpiece speed, tool speed and feed rate. Oysu and Bingul (2007) also used heuristic algorithms such as Simulated Annealing (SA), GA and hybrid algorithm (hybrid-GASA) which was applied to the tool path optimization problem in order to minimize the airtime during machining. The comparison between their performances was based on shortest path and minimum airtime which shows that the hybrid algorithm gave better results than other heuristic algorithms alone (Oysu and Bingul, 2009).

Liu *et al*. (2013) presented the optimum path of CNC turret typing system for reducing the changing tools times. They optimized the tool movement routes to make up the deficiency of CNC turret typing machine production efficiency. They used the polynomial model based on asymmetric traveling salesman problem and GA to solve the path optimization problem. The experimental result showed that the GA can decrease the processing time and reduced the air traveling without changing the machine's hardware through sensible arrangement of the varying and moving tools path (Liu *et al*., 2011).

On the other hand, Balic and Korosec (2002) presented ANN approach for prediction of milling tool-path strategy. Their proposed the ANN with sequence appropriation to find the best surface quality of machining surface at the free surface machining. In their case, the primary technological aim was to generate the best possible surface quality of machined surface (Balic and Korosec, 2002). Also Zuperl and Cus (2003) employed the ANN approach to increase the productivity and cost reduction for complex optimization of cutting parameters. Their proposed ANN is able to optimize the cutting parameters in order to find efficient machining process (Zuperl and Cus, 2003).

Moreover Zuperl *et al*. (2004) for complex optimization of cutting parameters for turning operation used hybrid optimization ANN and OPTIS routine. The result compare with other algorithms and approaches are found the better perform in term of the objective function values. Since the hybrid optimization can obtain near optimal solution for machining parameter selection of complex machined parts (Zuperl *et al*., 2004).

In the other research for high speed machining and high resolution manufacturing by Ülker E *et al.* (2009) which utilized new and powerful AI tool called Artificial Immune Systems (AIS) with Non-Uniform Rational B-Spline (NURBS). Their developed tool patches for reducing machining time and increased accuracy for a sculptured surface (Ülker *et al*., 2009). The result of their work demonstrated that the proposed AIS based tool path interval and step-size algorithm for NURBS can reduce the machining time and data while increasing the machining resolution. In minimization surface roughness of milling operation Mahdavinejad *et al*. (2012) employed AIS. In this study for find optimum parameters focus on different parameters such as cutting speed, depth of cutting and feed rate.

The researches of utilizing ACO also have taken interest from several researchers. For example, in minimize the summation of tool switching time and tool airtime in hole-making operation, Ghaiebi and Solimanpur (2007) used ants algorithm on TSP problems to solve the proposed mathematical model. In cutting optimization for multi pass turning operation Jing and Yingxue (2008) employed modified Machining ACO (MCACO). From the experiment results, it was found optimum process parameters to minimize the production unit cost (Jing and Yingxue, 2008). Meanwhile in optimize the process parameters of turning machining Cus *et al*. (2009) proposed ACO. In this research, the ACO technique focused on the reduce production cost and increase productivity. This approach used Adaptive Neuro-Fuzzy Inference System (ANFIS) and an ACO method to achieve the optimal parameters (Cus *et al*., 2009). Similarly, Abbas *et al*. (2010) applied the ACO algorithm to find the optimum path planning in CNC drilling machines for large number of holes. The holes were arranged in a rectangular matrix and they used two modifications and basic ACO algorithm to take advantage of the rectangular layout of the holes. Their result shows that their modified ACO algorithms worked efficiently than the basic ACO algorithm in reduction of total tool travel distance (Abbas *et al*., 2010). Medina-Rodriguez *et al*. (2012) used Parallel ACO in order to obtain an optimal tool travel path and determine the best sequence of G commands for a set of holes in a printed circuit board. They adapted ACO application as special case of the TSP (Medina-Rodriguez *et al*., 2012). It confirmed that the combination of algorithm based on Parallel ACO and TSP can be applied to any similar problem, such welding and tapping. Also Wang *et al*. (2012) focused in tool path optimization for group of holes drilling. In this research used graph theory of TSP based on ACO and Lin-Kernighan (LK) algorithm. In their result, they improved the precision and efficiency of the drilling process (Wang *et al*., 2012).

Meanwhile for drilling operation with CNC machines, Onwubolu and Clerc (2004) formulated the drilling operations as a TSP and used PSO to solve it. The technique of their proposed PSO required few control variables. The advantages of their technique are that it is multipurpose, robust and easy to use and hence reduction of production costs (Onwubolu and Clerc, 2004). Zŭperl *et al*. (2007) for optimize process parameters in milling machining employed ANN method for predict cutting force in during of machining and used PSO to find optimum process machining such as cutting speed and feed rate. Also Gao *et al*. (2008) in milling machining proposed PSO method and optimization algorithm for Cutting Parameters Optimization (CPO) to find optimum process parameters.

Junmei and Gaohua (2009) employed PSO method to find optimum process parameters in turning machining. In this study researcher find optimum cutting speed and feed rate which influence with increase machining accuracy and decrease machining time and machining cost (Junmei and Gaohua, 2009). In the optimization process parameters of CNC end milling Prakasvudhisarm *et al*. (2009) proposed PSO method to optimize characteristics of roughness and its factors which captured by Support Vector Machine (SVM). The result showed corporation between this two methods reached to the high surface quality and increase productivity (Prakasvudhisarn *et al*., 2009). In multi-pass turning Srinivas *et al*. (2009) employed PSO for selecting optimum machining parameters. In this research, researcher focus on reduce production cost and machining time (Srinivas *et al*., 2009). Also in optimize process of multi-pass turning Lee Yi and Ponnambalam used PSO. In the result for minimization unit production cost, PSO method compare with GA and SA methods (Zheng and Ponnambalam, 2010).

Also Hsieh and Chu (2012) proposed an Advanced Particle Swarm Optimization (APSO) and Fully Informed Particle Swarm Optimization (FIPSO) algorithms for a 5-axis milling machine to improve the quality of optimal solutions and search efficiency of the machining process. From the result, they found that FIPSO is most effective in reducing the error due to the capability to determine the next move with a particle utilizes information from all its neighbors rather than just the best one in PSO.

Other resech by Klancnik *et al*. (2012) in the automatic programming of a CNC milling machining that used PSO shows that the method can achieve a reduction machining costs and increased productivity in machining process. Also for find optimum machining parameters in face milling on aluminum material Raja and Baskar used PSO. In the result, the predicted roughness using PSO, shows the better result than the actual roughness (Bharathi Raja and Baskar, 2012).

OPTIMIZATION METHODS FOR MACHINING

In this study, based on the literatures that we surveyed, various types of optimization method used by researchers in reduction of cost, tool changing time and tool travel path, minimizing machining time, airtime, computation time and increase productivity and surface roughness as shown in Table 1. GA and PSO optimization methods principally used to improve machining parameters respectively as shown in Fig. 1.

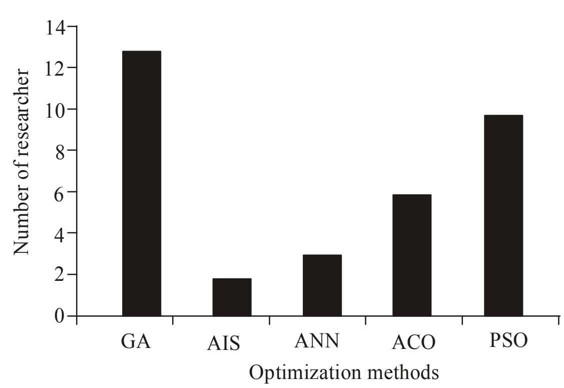

Fig. 1: Number of researcher used different optimization methods

Table 1: Shows which optimization methods used for improve machining factors in previous research

Authors, year	Optimization methods GA	AIS	ANN	ACO	PSO
Chen and Tseng (1996)	✓				
Dereli *et al*. (2001)	✓				
Balic and Korosec (2002)			✓		
Zuperl and Cus (2003)			✓		
Cus and Balic (2003)	✓				
Castelino *et al*. (2003)	✓				
Onwubolu and Clerc (2004)					✓
Zuperl *et al*. (2004)			✓		
Agrawal *et al*. (2006)	✓				
Qudeiri *et al*. (2006)	✓				
Oysu and Bingul (2007)	✓				
Qudeiri *et al*. (2007)	✓				
Ghaiebi and Solimanpur (2007)				✓	
Palanisamy *et al*. (2007)	✓				
Zŭperl *et al*. (2007)					✓
Saravanan and Janakiraman (2007)	✓				
Gao *et al*. (2008)					✓
Savas and Ozay (2008)	✓				
Jing and Yingxue (2008)				✓	
Oysu and Bingul (2009)	✓				
Junmei and Gaohua (2009)					✓

Authors, year	Factors Minimizing machining time	Increase productivity	Reduction of cost	Minimizing airtime	Reduction tool travel path	Shorter computation time	Reduce tool changing time	Increase surface quality
Chen and Tseng (1996)	●							
Dereli *et al*. (2001)		●				●		
Balic and Korosec (2002)								●
Zuperl and Cus (2003)		●	●					
Cus and Balic (2003)	●		●					●
Castelino *et al*. (2003)				●				
Onwubolu and Clerc (2004)			●		●			
Zuperl *et al*. (2004)	●	●	●					
Agrawal *et al*. (2006)	●							
Qudeiri *et al*. (2006)	●				●			
Oysu and Bingul (2007)				●				
Qudeiri *et al*. (2007)	●				●			
Ghaiebi and Solimanpur (2007)				●			●	
Palanisamy *et al*. (2007)	●							●
Zŭperl *et al*. (2007)	●							
Saravanan and Janakiraman (2007)	●	●						
Gao *et al*. (2008)	●							
Savas and Ozay (2008)								●
Jing and Yingxue (2008)			●					
Oysu and Bingul (2009)				●				
Junmei and Gaohua (2009)	●		●					

Authors, year	Optimization methods GA	AIS	ANN	ACO	PSO
Cus *et al*. (2009)				✓	
Ülker *et al*. (2009)		✓			
Prakasvudhisarn *et al*. (2009)					✓
Srinivas *et al*. (2009)					✓
Zheng and Ponnambalam (2010)					✓
Abbas *et al*. (2010)				✓	
Liu *et al*. (2011)	✓				
Medina-Rodriguez *et al*. (2012)				✓	
Wang *et al*. (2012)				✓	
Hsieh and Chu (2012)					✓
Mahdavinejad *et al*. (2012)		✓			
Bharathi Raja and Baskar (2012)					✓
Klancnik *et al*. (2012)					✓

Table 1: Continue

Authors, year	Factors: Minimizing machining time	Increase productivity	Reduction of cost	Minimizing airtime	Reduction tool travel path	Shorter computation time	Reduce tool changing time	Increase surface quality
Cus *et al*. (2009)		●	●					
Ülker *et al*. (2009)	●							●
Prakasvudhisarn *et al*. (2009)		●						●
Srinivas *et al*. (2009)	●		●					
Zheng and Ponnambalam (2010)			●					
Abbas *et al*. (2010)	●				●			
Liu *et al*. (2011)	●				●		●	
Medina-Rodriguez *et al*. (2012)					●			
Wang *et al*. (2012)	●				●			
Hsieh and Chu (2012)	●				●			
Mahdavinejad *et al*. (2012)								●
Bharathi Raja and Baskar (2012)	●				●			●
Klancnik *et al*. (2012)	●		●					

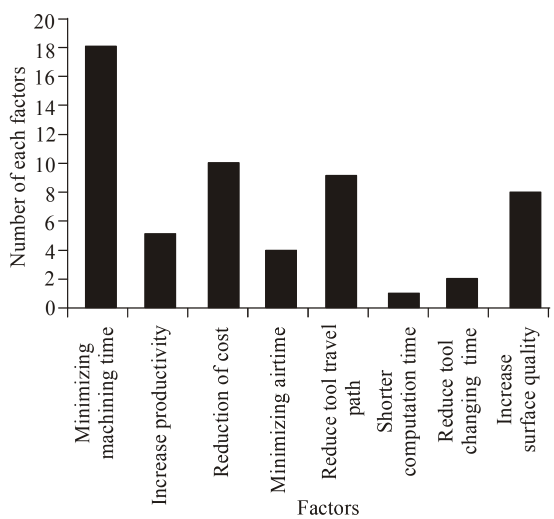

Fig. 2: Number of each factors optimized with researcher

Other method such as ANN was used to increase the productivity, surface quality and reduction of cost. On the other hand, PSO method was adapted to reduce tool travel path, reduction cost and minimizing machining time. ACO method was employed for minimizing machining time and air time, reduction cost production, tool travel path and tool changing time and increase productivity. Also small size of researcher employed AIS method for minimizing machining time and increase surface quality. According to the Fig. 2, in recent years researchers focused on improving four parameters, minimizing machining time, reduction of cost and tool travel path and increase surface quality on CNC machining for increasing the machining efficiency.

CONCLUSION

This study presented a survey of prior studies on tool path optimization with different types of methods such as ANN, GA, ACO, AIS and PSO. From our review, GA and PSO are largely used to optimize machining efficiency. When compared with other methods GA and PSO was most widely adapted to improve machining process. It can be ascertained from our results, the GA has been successfully applied for many optimization problem in various parameters related to tool path and effective in improving the robustness of feature selection over a range of problems.

Meanwhile the ACO method mainly utilized in minimizing machining time, airtime and reduction of tool travel path which targeted to find the shortest path in machining. On the other hand, the ANNs were used to increase productivity, increase surface quality and reduction cost. Other method PSO was mainly employed for the reduction of tool travel path, cost and minimization of machining time. From our review, the most important factor was the machining time because we found that all the AI optimization methods applied in purpose of minimizing it. This is because the machining time is an extremely effective factor in improving machining process.

For future study we suggest to use hybrid methods to find optimal machining parameters. Hybrids methods include two or more optimization methods in one research to find optimal machining parameters. For instate, use GA and ANN for reduce machining time, cost and computation time and increase productivity, surface quality together at the same time. In this type of research when compare to the other research used one optimization method the hybrid way appear more optimal result.

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