Application of Artificial Intelligence in CNC Machining Process Optimization

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***Abstract*—Today we are on the threshold of new industrial revolution through which digital networks are linked to the manufacturing operations. Real impact of AI in the next generation of industrial systems, namely Industry 4.0, the technologies have to be systematically developed and implemented. As of today, the machining parameters are controlled by the machinists in the job shops which are limited by their expertise and experience level. Excessive tool wear, poor surface quality incurs re-processing and higher waste generation which negatively impacts the production costs and profitability. The CNC machines can be equipped with AI technologies for better understanding of process control. This paper provides an insight to the current AI technologies which can be implemented in machining processes in order to manufacture high quality work pieces effectively.**

Keywords*—*Artificial Intelligence, Industry 4.0, CNC machine, Process Optimization

I. INTRODUCTION

Artificial Intelligence is a science with rich research activities in areas of image processing, machine learning, robotics, etc. The AI technologies were kept in dark due to lack of evidence that the technologies or techniques will work in real life and work consistently and return the investment. There is a rapid development in aerospace, automotive, power technologies, and the demand for high performance complex parts is increasing. For this, the multi axis Computer Numerical Control (CNC) machining processes is a popular choice. However, there are limitations in the dynamic properties for CNC machines which affect machine accuracy and the quality of the product.For Computer Numerical Control (CNC) machining, the process is dependent on the experience of the machinist and the programmer. This limits the production capacity and quality. Majority of the companies are still using machinist's experiences to control the process quality which leads to low efficiency and quality of production. In CNC machining processes, machine tool behaviour (thermal and vibrational), tool wear, geometric deviations and lastly machining parameters play important role in assuring surface quality of the workpiece and geometrical accuracy. In current manufacturing environment, the operations generate extra bills which can be avoided by using control systems. For sustainable performance, AI technologies should be deployed which can assist in determining process parameters, predict the surface quality and tool wear, maintaining the machine tool vibrations, thermal behaviour. The purpose of this work is implementation of AI technology in CNC machining to overcome majority of problems faced by the companies today.

As of today, multi axis CNC (Computer Numerical Control) machining is the most efficient way for manufacturing components that require precision. Normally CNC machine operates according to the G-code which is programmed inside the control system of the machine by the programmer. The CNC program provides the command to the processor unit which then operated the motor drivers which are responsible for axis travel. Motor drivers send the signals in the form of electrical pulses to the motor encoder through which motor operates. This operation is not simple as it seems as there are many challenges in maintaining the signal and remove the unwanted noise in signal which can cause deflections in actual measurements. For this, a closed loop feedback system is installed which recognises the error in axis travel and alignment and generates the compensation signals.Most of these closed loop feedback systems are already present in todays CNC machines. The challenges faced by todays job shops in machining operations is due to inefficient use of the machine capabilities. Main reason for this is lack of experience of the programmer.

There are other factors which affect the quality of the manufactured workpiece such as surrounding vibrations, thermal changes in surrounding as well as due to tool action on workpiece, etc.Surface quality and geometric precision are the most important factors that set the multi axis CNC machined components apart from the ones which are manufactured using other processes. In multi axis CNC machining process for high performance components with complex geometry, precision of the multi axis CNC machine tool is important for ensuring accuracy of the part thus assuring its usability and life. But due to excessive tool wear, thermal errors influenced by the cutting fluid used, and geometric deviations due to, quality of the machined component cannot be assured.

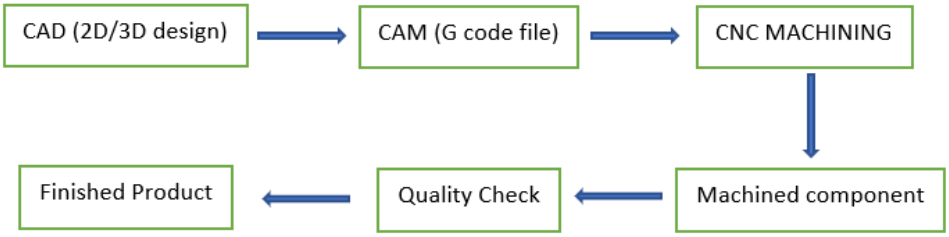

Fig. 1 Product development procedure

II. ARTIFICIAL INTELLIGENCE IN MACHINING PROCESSES

Artificial Intelligence based automation is yet to have noticeable impact on productivity growth. Besides this, industries are facing new challenges in terms of demand and competition. Integration with recent AI technologies like Industrial AI and other Intelligent Manufacturing Systems (IMS) such as machine learning, Artificial Neural Network based control systems, fuzzy logic systems, clustering, etc will enable industries to operate in efficient way. There are number of modelling techniques to provide a reference model to CNC machining process. These techniques are distinguished by their application and process approach. Other important factor in differentiating in modelling techniques is the algorithm they use. Different modelling techniques are discussed below in further detail.

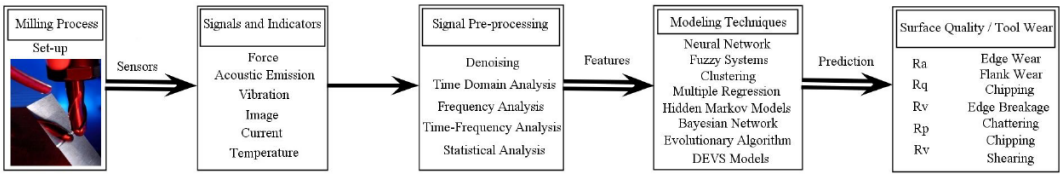

Fig. 2 Tool condition monitoring and surface roughness prediction [1]

A. *Bayesian Networks*

A Bayesian network (BN) is a graphical model which represents random variables and their probabilistic dependencies. It is one of the most famous decision-making methods used by operating on the statistical data of the process. A Bayesian network modelling method was used in [3] for surface roughness prediction. It was also used in [4] for tool wear and its performance characteristics. Force signals are used as inputs which were used in accuracy prediction. Also, in [2] acoustic study of spindle system of a CNC machine was used to study the acoustic emission of spindle.Bayesian Networks have been extensively used to determine the best cutting condition problemsas the process is graphically representable and the user can easily obtain the significant parameters in the process which directly affect the process and need to be optimized.

B. *Fuzzy logic, Neural Network based methods*

Artificial Neural Networks, Fuzzy logic and their combinations like Fuzzy Net (FN) are widely used in CNC machining processes particularly in HSM processes.

These methods are capable of producing accurate approximations of the surface roughness of the component [5,6,7,8,9,10,11]. Each study has applied ANN using different algorithms. However, the user can choose the best algorithm suited best for its application.

C. *Genetic algorithms, genetic programming*

This method of Genetic Algorithms (GA) is optimization-based method and is used where the machining parameters need to be optimized to obtain certain result. Basically, this is an adaptive method which creates the model based on the data available. This method is better at producing optimal solutions. With its ability to find optimal solutions to most of the nonlinear problems in machining processes, there is no limitation on using any predefined model for a particular problem.There are some studies merging dynamic learning methods with this method [13] and has scope for future studies. Since this method is restricted to the offline data-based modelling, it may not be applicable in problems that require online data processing and prediction models.

D. *Clustering and classification methods*

As the name suggests, this method uses grouping of similar data in clusters for a proper understanding of the domain. The clustering system is mainly divided into two types,

1. Hard clustering
2. Fuzzy clustering

In Hard clustering, the datum or an element can belong to only one type of cluster. This means, one element or a data point can be apart of only one cluster when using hard clustering.On the other hand, in fuzzy clustering, an element can be a part of many clusters which are in certain relationship. This states that an element can be a part of number of clusters with certain similarities, dependencies or connectivity [14,15].Fuzzy clustering is a famous technique which classifies finite information into several groups based on some criteria. Given this finite set of data, the cluster returns the cluster centres which are basically arithmetic mean of all its members. Each of the element has a specific value that belongs to a specific cluster. This method is applied in [16] to develop a method for modelling approaches.

III. APPLICATIONS

A. *Surface quality assurance*

Surface quality is the most important factor that assigns the machined nature to a component. Certain applications like aerospace, defence technology, etc require components which have superior surface quality to ensure its usability and performance. The surface quality cannot be assured depending solely on machinist's experience as the machining parameters have very complex effect on the surface roughness of the component. New approach deploying AI technologies in surface roughness prediction and real time monitoring systems can reduce the time required in quality check of the machined parts which have to pass certain surface roughness tests and boost the production and increase efficiency.Neural Network based methods are applicable in analysing the relationship between machining parameters and the surface roughness. By using this methods, optimum machining parameters are obtained in order to achieve minimum surface roughness in [17]. A neural network-based research in prediction of surface roughness of machined components at various speeds, feed rates and cutting depth is presented in [18].There are different approaches to optimize the process to obtain required surface quality; conventional or nonconventional. The conventional methods are linear programming, nonlinear programming, etc [19] or statistical methods like response surface methodology (RSM) [20,21,22]. Nonconventional methods nearly give an optimum solution and are based on genetic algorithm methods[23,24,25], neural network [26,27,28].To support real time monitoring during machine execution, use of digital image processing for prediction of surface roughness is presented in [29].

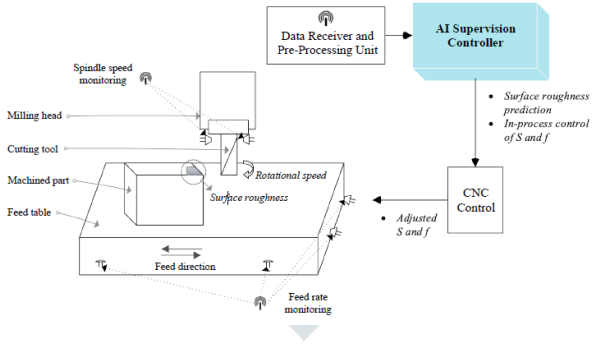

Fig.3 Supervision control for surface quality assurance[30]

In [30] innovative supervision control system consisting of surface roughness prediction model and multi variable controller is designed. In [31] the influence of cutting fluid temperature on surface roughness is studied.

B. *Tool wear monitoring system*

Tool wear monitoring is an important factor which ensures the process efficiency and quality. Moreover, the tool condition detection can help in reducing the hidden costs which cause shutdowns, quality issues or even injuries [31,32,33]. In [34] the process of retrofitting the CNC machine with programmable sensors to collect and process the machining data to optimize the tool wear is studied. In [34] ANN trained with 3 input vectors is developed with one hidden layer and a single output vector which is found to be computationally efficient. Combined with support vector regression (SVR), Bayesian Networks (BN) was applied in [35] to detect tool wear and enhance the performance. Input signals to both the networks were the force features which were compared through their prediction accuracy. In [36,37,38] Radial back functions (RBF), back propagation and dynamic propagation were compared to develop a single model to determine the best structure. Using only one hidden layer, the model was able to determine force features for given cutting conditions.

C. *Correcting geometric deviations*

With increasing complexity of the components used in aerospace, automotive and other industries, limitations of machine tool dynamics cause geometric deviations which affect the accuracy and the performance of the machined part. Thus, reducing geometric deviations becomes of great significance to achieve precision machining.The main sources that produce errors in CNC machining are,

1) Geometric deviations
2) Thermal errors
3) Errors due to spindle forces

The geometrical errors are generally produced due to misalignment in machine tool structure. As a result, the machine lacks in parallelism, straightness and flatness. These imperfections are carried on to the components which are manufactured on these machines. Thermal changes in machine tools are one of the largest contributors to the deviations and errors on machined workpieces. Up to 75% of geometrical deviations are caused due to thermal changes. Room temperature, cutting process, coolant effect, etc cause complex effect on the deviations caused in machining processes.In [39] thermal behaviour of machine tool is investigated. The behaviour with and without cutting fluid during the machining process is studied. It was observed that cutting fluid can positively affect the thermal behaviour of machine tool.

IV. CHALLENGES AND LIMITATIONS OF AI TECHNOLOGIES

To summarize the report, we have some obvious limitations and research gaps in the field that need to be addressed.

1) Processing power is the most important factor which limits the power of AI tools in machining. For online monitoring systems, the processing power of the system needs to be high in order to process the input signals, optimize the parameters and provide a final output. All these processes are to performed in fraction of time. If the system consumes more time in processing and optimizing the parameters, actual production will be negatively affected.
2) Machine to machine interaction is another challenge which can negatively affect the process optimization. As the machines are governed by the same system, the decisions taken for one machine for parameter optimization should not affect any other machine in the loop.
3) As the machines are connected to a network, there is always a threat of cyber attack and the system needs to be protected against such attacks. Consider a smart manufacturing plant based on cloud management. If any one of the process is under cyber-attack, the whole manufacturing facility can suffer a shutdown until the threat is resolved.

V. CONCLUSIONS

With increase in complexity of machined parts and requirement of high accuracy and surface quality used in aerospace, automotive and other industries, limitations of the dynamic properties of the CNC machines become a vital issue that affects the overall quality of production. The improvement in this area becomes of great significance for promoting the CNC motion systems. Application of AI technologies in machining processes is hotspot issue in machining engineering on which number of researches are being conducted. Applying AI technologies in CNC machining benefits the process with efficiency and quality. In this paper, state of the art CNC machining process optimization methods using Artificial Intelligence are comprehensively reviewed. All the representative techniques and technologies can be applied to multi axis CNC machines to improve the production rate and quality assurance. Advantages and shortcomings of these methods are classified and discussed based on which user can locate their interesting categories.

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