Control Strategies for CNC Machine Tools

Classification, Comparison and Future Trend

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Abstract— ***In this paper, various controlling techniques used to control Computer Numerical Control (CNC) machine have been studied. They are designing and implementation of PID controller, PD controller, linear quadratic regulators, and Fuzzy Logic controller for control operations for CNC machine, based on Artificial Intelligence Techniques.***

***Index Terms*—Conventional PD, PID Control, LQR control, CNC, AI based control, Fuzzy logic, Artificial Intelligence.**

I. Introduction

John Parsons, with MIT Servomechanism Lab. [1] was the first one to introduce this concept of Numerically Controlled machine tool in 1950s. Later, in seventies, Computer aided Numerical Control was introduced that will be discussed here in after. Computer Numerical Control (CNC) machines come under automated industry basically performing milling operations in which no human interference is required. It is connected to a computer network through which coded cutting and trading related instructions are provided so that assembling of parts is done and fabrication is achieved precisely and quickly. There can be different types of CNCs, like drills, plasma cutters etc. for manufacturing a wide quality of products. Most commonly used machines are like milling, lathes and grinders machines by which task like cutting, threading, giving shape of metals are performed accordingly. This paper focuses on the servo-control, other than the interpolator control; wherein many techniques have been proposed by various authors till date.

The most common and easily implementable PID controllers were given initially, considered as conventional controller. But in certain applications comprising imprecise input-output relationships with unknown disturbances, PID controlling method is inadequate [2-3].

Later, with the assiduous and aggressive efforts, some more effective methods were postulated discussed below, which could take care of the frictional or the contour errors of CNCs [4-5].

A new scheme known as self-organizing fuzzy logic controller for wheeled mobile rotor using evolutionary algorithm has been suggested by Kim *et al.* [6]. As fuzzy controller alone was not able to provide many features of adaptive controller both were together used for different control problems [7]–[10]. Next the state feedback control technique such as LQR controller of optimal control segment came up with beautiful features to improve dynamic as well as steady state performance [11]–[14].

The key element is optimization of parameters. Genetic algorithm is widely used due to conquering the deficiency of gradient based optimization. It is suitable for non-linear function.

II. Control Strategies

PID Controller

In realizing control theory networks problems, when a plant or system is designed or based on long differential equations and unknown non-linear parameters which are tough to resolve. Therefore, proportional – plus – integral – plus – derivative (PID) is best option for real time operations and in control systems operations due to its easy implementation and excellent working in closed-loop industrial processes. To implement a PID, we have three factors to be varied interchangeably, each imposing its characteristic effect on the system's performance. Proportional gain (K_p) is used to achieve fast response and improve the precise points of control. Integral gain (K_i) helps removing offset, if any, but results in oscillations in steady state response. Derivative gain (K_d) helps in overcoming the overshoot problem and minimizing the oscillations of steady state response of system that causes instability. The transfer function of PID is given below:

$$C(s) = k_p + \frac{k_i}{s} + k = k_p\left(1 + \frac{1}{\tau_i s} + t_d s\right)$$

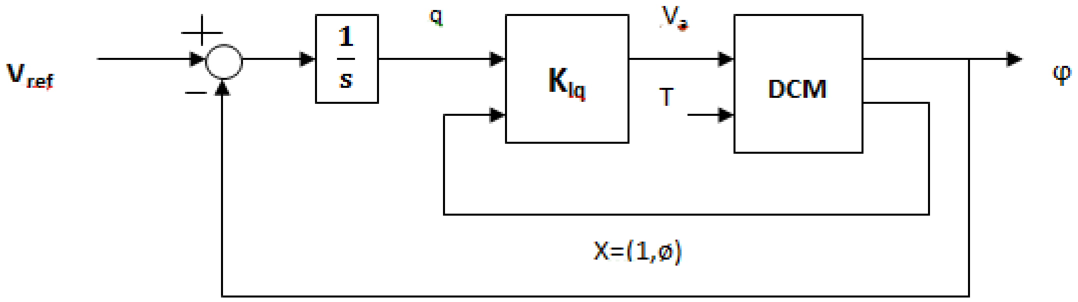

Fig. 1 LQR Controller

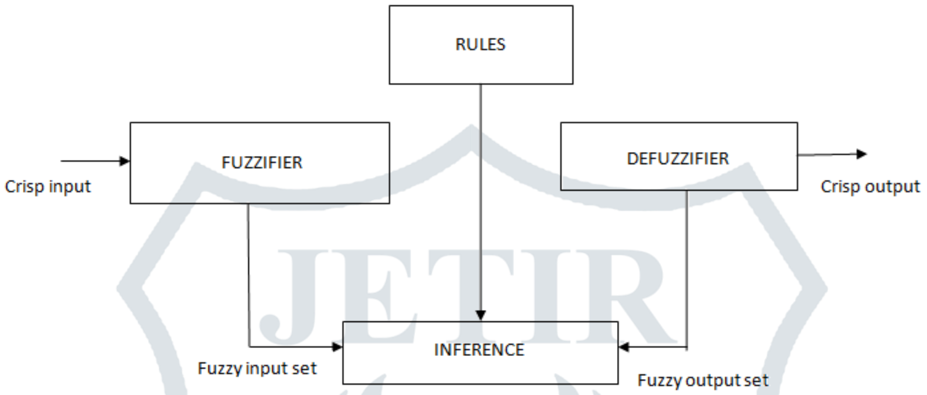

Fig. 2 Fuzzy Logic Controller

Linear Quadratic regulator

Linear quadratic regulator or LQR technique comes under optimal control system that uses state space approach to obtain the stability or instability of system, and analyze the system behavior. The block diagram of LQR is shown in Fig. 1.

Pushpkant *et al.* [15], proposed the control theory of state space approach to analyze a system in LQR. It is relatively simple to work with multi-output system LQR based control scheme. It gives comparatively better performance in terms of overshoot, rise time, settling time and steady state error.

Using MATLAB software, LQR controller model can be designed to determine the value of vector K which is feedback source. Nbar, a value of constant gain is used to reduce the steady state error of output of the system. It can be obtained by user defined functions.

Fuzzy Logic Controller

FLC has proven to be an efficient method for handling systems with inexact information on the basis of reasoning. It enables the engineer to convert knowledge expressed in uncertain linguistic form into an exact algorithm. Fuzzy logic controller consists of four main parts which are fuzzification, set rule base, inference engine and de-fuzzification respectively. Fuzzification consists of membership functions that fuzzifies the input data. It can be triangular function, rectangular function and trapezoidal function. The set rule base is collection of conditions in the form of IF-Then rules that depend on input-output relationship of the system. Inference engine is the stage where output is governed according to rule base, then after, data is defuzzified and control operation is achieved. The schematics diagram of fuzzy logic controller is given in Fig. 2.

It is very simple and user friendly and takes less computing time. It is the source of combining the linguistic variables and control theories.

III. Future trends

Artificial intelligence techniques have been an area of interest for the research work for over a decade. Fuzzy logic base controllers were initially designed and were tested in various applications [16] but, since fuzzy logic controllers usually have more adjustable parameter in the rule consequent, therefore, manual tuning of these parameters could be ineffective, inefficient, or sometimes impossible when there are many parameters to adjust. Neural network was another approach used for function approximation. However, as in other approaches that learn to control through experiments, some serious problems remained, such as need and reliability of learned rules, as well as robustness.

Neuro-fuzzy systems, as hybrid system, have become popular in the last decade. They are combinations of the theories of fuzzy logic & neural networks. In contrast to the pure neural or fuzzy system the fuzzy neural networks (FNN) possessed both their advantages; it combined the capability of fuzzy reasoning in handling uncertain information and the capability of artificial neural networks in learning from processes. In these systems, the parameters of fuzzy system are determined by means of learning algorithms used in neural network. Wai *et al.* [17] established the superior performance of Neuro-Fuzzy Controllers at various operating points of the boost converter. The basic concept Of Neuro-Fuzzy Control method was first to use structure learning algorithm to find appropriate Fuzzy logic rules and then use parameter-learning algorithm to fine-tune the membership function and other parameters. But still the requirement of prior knowledge of process could not be ruled out.

To resolve these problems, the application of genetic algorithms to both learning controller structure from scratch and tuning controller parameters was explored [18]. Genetic algorithms (GA's) are search procedures inspired by the laws of a natural selection and genetics. They can be viewed as a general-purpose optimization method and have been successfully applied to search, optimization and machine learning tasks. It has been already shown that GAs can learn to control a dynamic system without any prior knowledge about the system. Following which, the hybrid controllers came into picture where 2 or more of such techniques were combined together. A genetic-algorithm-based fuzzy-knowledge integration framework was given that can simultaneously integrate multiple fuzzy rule sets and their membership function sets [19]. The proposed approach consisted of two phases: fuzzy knowledge encoding and fuzzy knowledge integration. In the encoding phase, each fuzzy rule set with its associated membership functions is first transformed into an intermediary representation and then further encoded as a string. The combined strings form an initial knowledge population, which is then ready for integration. In the knowledge-integration phase, a genetic algorithm is used to generate an optimal or nearly optimal set of fuzzy rules and membership functions from the initial knowledge population**.** Results showed that the fuzzy knowledge base derived using this approach performs better than every individual knowledge base. A genetic algorithm for real-time control optimization problems to optimize the rule consequent parameters of a Takagi-Sugeno (TS) fuzzy controller was explored in [20].

Leng *et al.* [21] proposed a novel hybrid algorithm based on a genetic algorithm to design a fuzzy neural network, named self-organizing fuzzy neural network based on GAs (SOFNNGA), to implement Takagi–Sugeno (TS) fuzzy models. One of the main novelties of the proposed approach was that the model was built for a system without a priori knowledge about the partitions of input space and the number of fuzzy rules. Lin *et al.* [22] successfully demonstrated the applications of a GA-based RFNN control system to the periodic motion control of an LIM servo drive. A nonlinear PID controller based on genetic tuning algorithm was designed by Luo *et al.* [23].

Li *et al.* [24] proposed a double chains quantum genetic algorithm (DCQGA), and showed its application in designing neuro-fuzzy controller. Quantum genetic algorithm (QGA) is a probability optimization algorithm based on quantum computation concept and theory. In a QGA, the chromosome is encoded by qubits and updated by quantum rotation gate, which can achieve an evolutionary search. Recently, some QGAs have been proposed for some combinatorial optimization problems, such as travelling salesman problem, knapsack problem, and filter design.

IV. CONCLUSION

This paper review intended to study and give the progress details in machine tool control since its invention in the mid-1950s. Also, some of the future scope of work that could be applied on the Machine tool for precise contour and servo control have been suggested which belong to modern world of artificial intelligence.

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