Applied Soft Computing 37 (2015) 114–124

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

A PNN self-learning tool breakage detection system in end milling operations

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ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form 9 August 2015
Accepted 10 August 2015
Available online 19 August 2015

Keywords:
Probabilistic neural network
Self-learning
Tool breakage
End milling operations

ABSTRACT

With the advance of technology over the years, computer numerical control (CNC) has been utilized in end milling operations in many industries such as the automotive and aerospace industry. As a result, the need for end milling operations has increased, and the enhancement of CNC end milling technology has also become an issue for automation industry. There have been a considerable number of researches on the capability of CNC machines to detect the tool condition. A traditional tool detection system lacks the ability of self-learning. Once the decision-making system has been built, it cannot be modified. If error detection occurs during the detection process, the system cannot be adjusted.

To overcome these shortcomings, a probabilistic neural network (PNN) approach for decision-making analysis of a tool breakage detection system is proposed in this study. The fast learning characteristic of a PNN is utilized to develop a real-time high accurate self-learning tool breakage detection system. Once an error occurs during the machining process, the new error data set is sent back to the PNN decision-making model to re-train the network structure, and a new self-learning tool breakage detection system is reconstructed. Through a self-learning process, the result shows the system can 100% monitor the tool condition. The detection capability of this adjustable tool detection system is enhanced as sampling data increases and eventually the goal of a smart CNC machine is achieved.

1. Introduction

To the modern automation industry, computer numerical control (CNC) machine provides more convenient operations than traditional NC because of its capability of not only performing traditional numerical control but also using CPU to control various machining operations. CNC machining provides high precision and accuracy to satisfy the needs of customers in quality. However, the machining processes of CNC are dynamic and can be changed at any moment. One of the significant factors is the cutting tool condition. The broken or worn cutting tool would influence the quality of products and may damage the machine [29]. To ensure the quality of products and the condition of cutting tool, a real-time tool monitoring system for CNC machining is developed.

The development of an effective tool monitoring system is of great value to the automation industry [13]. Over the years, various types of real-time tool monitoring system have been developed in different machining processes. Liao et al. applied acoustic emission signals with different methodologies, such as hidden Markov model-based clustering methods [22], a wavelet-based method [24], boosted minimum distance classifiers [23], and ant colony optimization for feature selection [21], to monitor the tool conditions for grinding operations. Ghani et al. used strain gauge to monitor the force signals, and implemented a statistical analysis to detect the tool conditions in a turning operation [11]. Rizal et al. applied neuro-fuzzy technology to monitor the tool wear in turning process [30]. Ahilan et al. integrated hybrid decision making tools to monitor the cutting quality in the turning process [1]. Patra et al. applied current signals with artificial neural networks to predict tool flank wear in a drilling operation [28]. Panda et al. used force, vibration and torque signals to predict flank wear in drilling operations [26]. Wang et al. used force signals to detect the tool wear in milling process [33,34]. Bassiuny and Li implemented the Hilbert–Huang transform function to analyze the motor current and judge the tool condition [4]. These references indicate the importance of a real-time monitoring system in traditional machining operations. Because a machining operation is very costly, it should be done as a last resort. Under the circumstance, the quality of machining should be ensured as quickly as possible. That is why the real-time tool monitoring system has to be studied

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http://dx.doi.org/10.1016/j.asoc.2015.08.019
1568-4946/

and implemented in industries. Among the machining processes, the milling operations have been frequently applied in automobile industry. The studies of a real-time tool monitoring system for milling operations have been widely discussed. In 2000, Chen and Jen used a fusion approach to combine raw data obtained from the dynamometer and accelerometer and train them in the neural network to monitor the tool condition in CNC end milling operations [8]. Also in 2004, Haber et al. used time domain and frequency domain analysis to compare the size variation and signal sensitivity, and to analyze tool wear in high speed operations [14]. Cho et al. used multi-sensors to measure end milling signals, and also support vector regression (SVR) to detect tool breakage in end milling operations. It was discovered that SVR produces higher accuracy compared to multivariate regression analysis [9].

In milling operations, the tool breakage has huge impact on end milling operations, many tool breakage studies focus on its application in milling operations [3,6,9,15,20,25]. An end milling operation is a machining process in which a work part on the milling machine is fed into a rotating milling cutter with a series of blades on the edge to remove metal materials. Milling machines are the most widely used machines which produce extremely smooth and accurate finish. By using various independent cutting tools and controlling the platform's different moving directions (e.g. rotation), end milling can form all kinds of angles, slots and gears in the work part [10]. Machining is a process in which a cutting tool is used to cause plastic deformation in a work part, making the work part peel to form a chip. Therefore, during the machining process, the cutting tool is subjected to a resistance, called cutting force, from the work part. The direction and magnitude of the cutting force varies depending on the type of machining process, tool angle, cutting conditions and work part material [18].

A real-time tool condition monitoring system consists of two components: the sensing technology and a decision-making model. In milling operations, the cutting force detected by a force sensor is a significant factor to determine the tool condition. Chen and Huang indicated the maximum peak force and the peak force between adjacent teeth could be analyzed to distinguish a good tool from a broken one [7]. Cakir and Isik mentioned the tool condition is difficult to build into a mathematic model, and the change of cutting force is a good indicator to monitor the tool condition [5]. Kious et al. applied cutting force signals to monitor tool wear in high speed milling operations [19]. Girardin et al. integrated cutting force and spindle rotational frequency to monitor tool wear and breakage [12]. In summary, the force signals are very effective in the detection of tool conditions in milling operations.

The second component of a real-time condition monitoring system is the decision-making model. An artificial neural network (ANN) has been widely applied as a decision making model for cutting tool detection [3,8,16,26]. The ANN is a computational simulation model inspired by a biological neural system. It enables a computer to perform machine learning and decision-making, the capability that is known as artificial intelligence. From the literature, most of the studies implemented the back-propagation neural network (BPNN) as a decision-making model for the monitoring system. However, the BPNN needs a large amount of data and time to train the network. Furthermore, once the model has been constructed, and the weight between each neuron has been achieved, the model cannot be modified. Therefore, if some new situations of machining happened during the real-time monitoring, the system could not be updated, and the error would happen again. To solve this issue, a probabilistic neural network (PNN) was proposed to develop a quick model training and self-learning tool condition monitoring system.

The purpose of this study is to develop a real-time self-learning CNC tool breakage detection system using the combination of sensor technology and a decision-making model. First, a supervised learning network processes the input factors, which are the machining parameters and the signals obtained from the force sensor, to detect the tool condition. Once error detection occurs, the data set, which includes both input and output factors, is sent back to the decision-making model to be re-trained. A higher accuracy real-time self-learning tool detection system is eventually derived from the detection pattern described above. The feature of the system is that it is able to send data set back to the network to be re-trained when an error occurs. This significantly lowers the overall error rate to achieve a more accurate in-process tool breakage detection system.

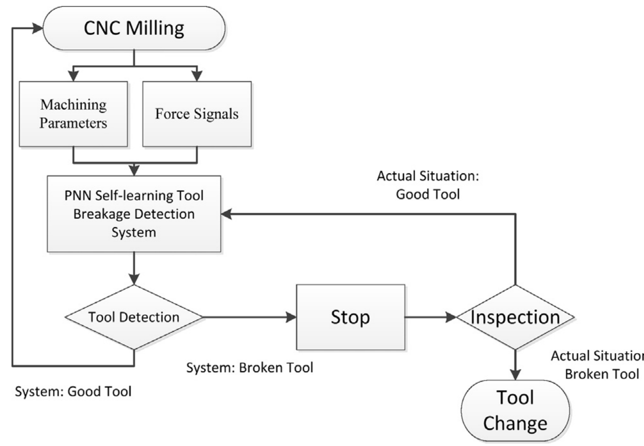

Fig. 1. A PNN self-learning tool breakage detection system.

This study is going to construct a real-time self-learning tool breakage detection system which allows the machine to detect tool breakage while operating, and to stop the operation in time to adjust the cutting conditions as needed to improve product quality and to eliminate unnecessary waste. However, many factors can affect the detection accuracy of the system. These factors, which include the type of CNC end milling process, cutting force and data processing method, are discussed in the following sections.

2. The principles of self-learning

The main objective of this study is to construct a self-learning tool detection system, an extension of the real-time tool monitoring system. The system sends the error data set of the tool detection back to the training network to be re-trained in order to increase its detection accuracy. This training network applies the probabilistic neural network (PNN) as its primary training method for a decision-making model. The most important feature of the system is that it can be implemented during operations, which reduces waste in production and labor caused by machine shutdown to check the tool manually, and achieves upmost efficiency in CNC end milling operations. The system block diagram of a PNN self-learning tool breakage detection system is shown in Fig. 1.

2.1. Cutting force analysis

Based on the self-learning tool breakage detection system shown in Fig. 1, and the literature discussed in Section 1, to develop an accurate tool detection system in an end milling operation, force signals collected from sensor are recommended. In an end milling operation, the cutting force in XY plane is an interrupted force, which increases when the cutter merges into the material, and decreases as the cutter passes through the center of the material. The force signal looks like a peak for each cutting tooth. Since the