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ORIGINAL ARTICLE

Cutting force-based adaptive neuro-fuzzy approach for accurate surface roughness prediction in end milling operation for intelligent machining

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Abstract End milling is one of the most common metal removal operations encountered in industrial processes. Product quality is a critical issue as it plays a vital role in how products perform and is also a factor with great influence on manufacturing cost. Surface roughness usually serves as an indicator of product quality. During cutting, surface roughness measurement is impossible as the cutting tool is engaged with the workpiece, chip and cutting fluid. However, cutting force measurement is easier and could be used as an indirect parameter to predict surface roughness. In this research work, a correlation analysis was initially performed to determine the degree of association between cutting parameters (speed, feed rate, and depth of cut) and cutting force and surface roughness using adaptive neuro-fuzzy inference system (ANFIS) modeling. Furthermore, the cutting force values were employed to develop an ANFIS model for accurate surface roughness prediction in CNC end milling. This model provided good prediction accuracy (96.65 % average accuracy) of surface roughness, indicating that the ANFIS model can accurately predict surface roughness during cutting using the cutting force signal in the intelligent machining process to achieve the required product quality and productivity.

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1 Introduction

Machining processes are fundamentally complex, nonlinear, multi variate, and often subjected to various unknown external disturbances. A machining process is usually performed by a skilled operator who uses decision-making capabilities based on the intuition and rules of thumb gained from experience. This process is not accurate enough and in many cases product faults occur. For this reason and to realize highly productive and flexible machining, a reliable, automated machining system with intelligent functions (intelligent machining) is needed [1, 2]. Figure 1 depicts the concept of an intelligent CNC machine. Intelligent NC machine tools have three feedback loop levels for intelligent functions. Among the intelligent functions, cutting force monitoring is an important issues, as it can tell the limits of cutting conditions, workpiece surface quality, and tool wear, as well as detect and prevent tool breakage and chatter, compensate tool deflections, and optimize machining processes through a model-based adaptive control system and other process information, which are indispensable for process feedback control [3–6].

In this research work, cutting force is used to predict surface quality during cutting in an end milling process. Surface quality plays a vital role in milled surfaces by significantly improving fatigue strength, corrosion resistance, and creep life. Moreover, surface quality affects several functional attributes of parts, such as contact causing surface friction, wear, light reflection, heat transmission, ability of distributing and holding lubricant, coating, and resisting fatigue [7, 8].

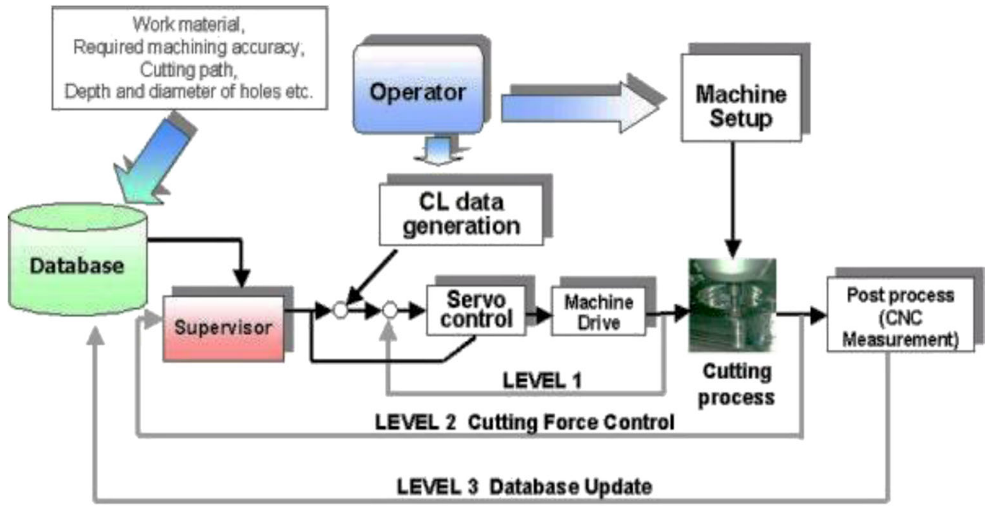

Fig. 1 System configuration of the intelligent NC machine tool [1]

To achieve higher levels of surface quality, correlation modeling of cutting force and surface roughness is required [9–11]. Modeling based on cutting force and surface roughness data is accomplished by soft computing tools [12–14]. Soft computing techniques are useful when exact mathematical information is not available and these differ from conventional computing in that they are tolerant of imprecision, uncertainty, partial truth, approximation, and met heuristics [15, 16]. ANFIS is one of the soft computing techniques that play a significant role in input–output matrix relationship modeling. It is used when subjective knowledge and expert suggestions are significant to defining objective function and decision variables. ANFIS is ideal to predict surface roughness based on input variables due to the nonlinear condition in the machining process [17–21].

As a conclusion of the above review, the aim of the present work is to investigate the use of cutting force-based ANFIS modeling for accurate surface roughness prediction in end milling operation for intelligent machining.

2 Experimental setup

The experimental setup is shown in Fig. 2. The experiments were performed using a CNC end milling machine. A high-speed steel four-flute end milling cutter with a diameter of 7/16 in (11.1 mm) was used for dry machining slots of Brass (60Cu40Zn) blocks under specific machining conditions, as shown in Table 1. These machining conditions were selected based on the tool maker's recommendations. Brass material with Vickers hardness of 125 and chemical composition of 60 % Copper and 40 % Zinc was used as workpiece material with 40×40×20 mm dimensions.

The surface roughness (*Ra*) was measured with a stylus-based profilometer (Surtronic 3+, accuracy of 99 %). The average surface roughness was calculated for three different measurements under the same conditions with a sampling

Fig. 2 Experimental setup