國立中興大學機械工程學系研究所

碩士學位論文

基於深度類神經網路於彈性約束多目標優化 CNC 控制器參數之應用

Application of Deep Neural Network to Flexible Constrained Multi-objective Optimization of CNC Controller Parameters

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中華民國 一○九 年 八 月

摘要

因應客製化產品及少量多樣的生產需求，如何快速且精確的調整 CNC 控制器參數，使其與現時機台的動態特性達到更佳機電匹配，以提升現有機台的動態加工效率與精度，在製造產業中扮演著重要角色。問題是，各家機台的構型動態特性與使用年限的健康狀態也不同，工程人員如何在加工時兼顧機台壽命、加工效率與加工品質等加工指標問題，如何在三者間會互相牴觸的情形下滿足多目標的加工要求，是工程人員的挑戰。最後一個問題是，工具機搭配的各家控制器各有不同控制參數，參數數量龐大且參數間交互作用，這更加深了現場工程人員在調整 CNC 參數的困難度。

本研究希望在系統化與學理根據下，建立 AI 模型來快速並精準的調整加工參數。首先是依據實際機台的現時健康狀態，讓機台執行標準運動圖案（test pattern）程式，取得實際機台運動動態資料，接著利用深層學習類神經網路，對機台動態運動數據自動學習與動態調整 CNC 參數。此外，目前關於 CNC 控制器參數優化之相關研究，大多以單目標優化形式為主，較不符合業界需同時兼顧機台壽命、加工效率與加工品質的多目標要求。因此，本研究提出深層學習類神經網路結合基因演算法搭配彈性約束優化技術，能同時考慮並準確預測到速度、精度、表面品質的三項指標，來預先得知機台加工結果。

AI 技術的產業應用必需要先能做到 Automatic data retrieving and Automatic data labeling（自動化資料蒐集與自動化資料標註），否則數據需要人工做資料標註處理就無法自動化。本研究讓 CNC 工具機執行一個稱之為 CNC 機台健康檢查與溫機程式的標準運動圖案，並藉由電腦自動蒐集 CNC 控制器、進給系統、伺服系統與相關的位移、速度與加速度資訊，然後透過自動化資料標註功能，自動估算出進給軸的輪廓誤差與進給軸伺服追隨誤差並完成資料標註工作。

為了減少在實際機台執行大量與耗時的學習數據擷取工作，以實際機台田口法

及隨機參數實驗執行標準運動圖案，並擷取機台的進給系統、伺服系統與相關的位移、速度與加速度資訊，建立深層學習類神經網路與遺傳基因演算法，可以隨時更新且符合機台最新健康狀態的 AI 模型，我們稱之為 Life-cycle-updated AI model，如此可以達到少量訓練資料之目的。

本研究也提出彈性約束優化之技術，達到多目標優化的功能，並於多目標優化找出 Pareto 最優解集（Pareto-optimal set），提供更多的加工性能選擇。彈性約束優化之技術能根據使用者的加工要求，設定各種不同需求下三項指標之數值，給予速度、精度、表面品質限制，在不同的三項指標限制下找出符合使用者加工要求的最佳參數組合，使用者能利用限制條件下的最佳參數組合進行加工來達到加工要求之目的。

本研究於達佛羅公司的 MCU-5X 五軸工具機搭配海德漢公司的 TNC640 控制器進行實驗。實驗過程中，機台數據資料蒐集約 2~3 小時、加工指標的自動化標註約 10~20 分鐘，並將標註完成之數據於 Python 中 Tensorflow、Keras 架構下所建構之類神經網路進行訓練，其訓練過程約 5~10 分鐘，最後應用 DEAP 遺傳基因演算法框架進行參數優化，其優化過程約 30 秒，從實際機台數據的蒐集到求出最佳化參數僅需不到 1 天的時間即可完成，大幅的改善參數調整效率。本研究實際機台類神經網路模型在菱形路徑的時間指標平均預測誤差為 0.58%、精度指標平均預測誤差為 5.24%、品質指標平均預測誤差為 1.53%；圓弧四邊形路徑的時間指標平均預測誤差為 0.52%、精度指標平均預測誤差為 6.21%、品質指標平均預測誤差為 1.72%；Kakino 路徑的時間指標平均預測誤差為 0.44%、精度指標平均預測誤差為 4.96%、品質指標平均預測誤差為 1.86%。實際機台類神經網路模型對於三項指標的預測皆有不錯的能力，並結合遺傳基因演算法使用彈性約束技術在多目標加工要求下，能有效依照設定的限制條件搜尋符合限制條件下的最佳參數組合。

【關鍵字】CNC 控制器參數調整、田口實驗方法、類神經網路、基因演算法、約束優化、多目標優化

Abstract

In response to customized products and small quantities of diverse production needs. How to quickly and accurately adjust the CNC controller parameters to better match the dynamic characteristics of the current machine to improve the dynamic processing efficiency and accuracy of the existing machine plays an important role in the manufacturing industry. The problem is that the configuration dynamic characteristics of each machine and the health status of the service life are also different. It is a challenge for engineers to consider how to balance machine life, processing efficiency and processing quality and other processing index issues during processing, and how to meet multi-objective processing requirements when the three are in conflict with each other. The last problem is that each controller with a machine tool has different control parameters, the number of parameters is huge and the interaction between the parameters, which makes it more difficult for the field engineers to adjust the CNC parameters.

This research hopes to establish an AI model to quickly and accurately adjust processing parameters based on a systematic and academic basis. First, according to the current health status of the actual machine, let the machine execute the standard test pattern program to obtain the actual machine motion dynamic data, and then use the deep learning neural network to automatically learn the dynamic motion data of the machine. Dynamically adjust CNC parameters. In addition, most of the current researches on CNC controller parameter optimization are based on single-objective optimization, which is not in line with the industry's multi-objective requirements that simultaneously take into account machine life, processing efficiency and processing quality. Therefore, this research proposes that deep learning neural network combined with genetic algorithm and flexible constraint optimization technology can simultaneously consider and accurately

predict the three indicators of speed, accuracy, and surface quality to know the machine processing results in advance.

The industrial application of AI technology must first be able to achieve automatic data retrieving and automatic data labeling, otherwise the data needs to be manually processed and cannot be automated. In this research, the CNC machine tool executes a standard motion pattern called CNC machine health check and warm machine program, and automatically collects CNC controller, feed system, servo system and related displacement, speed and acceleration information through the computer. , And then automatically estimate the contour error of the feed axis and the servo follow error of the feed axis through the automatic data labeling function and complete the data labeling work. In order to reduce the large and time-consuming learning data acquisition work performed on the actual machine, the standard motion pattern is implemented by the actual machine Taguchi method and random parameter experiments. And capture the machine's feed system, servo system and related displacement, speed and acceleration information, establish a deep learning neural network and genetic algorithm, which can be updated at any time and conform to the latest health state of the machine AI model, we Call it Life-cycle-updated AI model, so it can achieve the purpose of small amount of training data.

This research also proposes the technology of elastic constraint optimization to achieve the function of multi-objective optimization, and find the Pareto-optimal set in multi-objective optimization to provide more processing performance options. The technology of flexible constraint optimization can set the values of the three indicators under various requirements according to the processing requirements of the user, and limit the speed, accuracy, and surface quality. Optimal parameter combination, users can use

the best parameter combination under restricted conditions to process to achieve the processing requirements.

In this study, MICROCUT's MCU-5X five-axis machine tool was used with HEIDENHAIN's TNC640 controller for experiments. During the experiment, the machine data was collected for about 2 to 3 hours, and automatically annotated for about 10 to 20 minutes. The labeled data was trained on a neural network such as Tensorflow and Keras in Python. The training process is about 5~10 minutes, finally apply the DEAP genetic algorithm framework to optimize the parameters, the optimization process is about 30 seconds, from the collection of the actual machine data to the optimization parameters, it only takes less than 1 day to complete. Greatly improve the efficiency of parameter adjustment. In this study, the average prediction error of the time index on the diamond path of the neural network model such as the actual machine is 0.58%, the average prediction error of the accuracy index is 5.24%, and the average prediction error of the quality index is 1.53%；The average prediction error of the time index of the arc quadrilateral path is 0.52%, the average prediction error of the accuracy index is 6.21%, and the average prediction error of the quality index is 1.72%；The average prediction error of the time index of Kakino path is 0.44%, the average prediction error of the accuracy index is 4.96%, and the average prediction error of the quality index is 1.86%. The actual machine's neural network model has a good ability to predict the three index, and combined with genetic algorithm, flexible constraint technology can be used to effectively search for the best parameter combination that meets the constraints under the multi-object processing requirements according to the set constraints.

【Keywords】CNC controller parameter adjustment, Taguchi Method, Artificial Neural Network, Genetic Algorithm, Constrained Optimization, Mutli-objective Optimization