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碩　士　論　文

基於深度遷移學習之
滾珠螺桿差別運轉條件預壓監測研究

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摘　要

滾珠螺桿作為精密機械及工具機的重要零組件，預壓狀態的監測極為重要，預壓失效及背隙產生影響定位精度。本研究目的在於提出小樣本數據擴增技術及深度遷移學習(Deep Transfer Learning)應用在滾珠螺桿預壓狀態監測方法，使用(Generative Adversarial Network, GAN)模型做數據擴增(Data augmentation)，處理滾珠螺桿預壓數據不足問題；以深度遷移學習方法提升模型預測準確率，能夠在螺桿載台不同載重條件分類導螺桿預壓狀態。本論文分為四部分－(1)實驗規劃及數據收集：螺桿載台做等速往返運轉，收集30 kgw 砝碼及負載螺桿模組兩種不同載重螺桿振動訊號，實驗設計 4%、1%預壓及 12 μm 背隙共 3 種預壓狀態螺桿以建立判斷基準，其中 30 kgw 砝碼負載收集個別預壓狀態2500 筆資料，負載螺桿模組則為 500 筆，分別作為源域(Source domain)及目標域(Target domain)數據；(2)振動訊號分析及探討：藉由頻譜及包絡譜分析，探討個別預壓狀態與螺桿振動之間關係，解析振動訊號特徵頻率及產生原因，當預壓衰退或背隙存在時，除滾珠振動造成的球通頻率(Ball pass frequency)外，另有多個邊頻分量，即螺桿運轉時，滾珠撞擊產生振幅調變現象；(3)數據擴增模型建立：探討所提出的 GAN 架構性能，以 500 筆 30 kgw 砝碼負載 4%螺桿預壓訊號，訓練模型生成並建立數據集，以原始 4%預壓振動訊號特徵建立人工模擬訊號，後分別以卷積神經網路(Convolutional Neural Network, CNN)、多層感知機(Multilayer Perceptron, MLP)與極限梯度提升(eXtreme Gradient Boosting, XGBoost)等三種分類模型比較模擬、生成訊號做數據擴增的模型準確率；(4)遷移學習模型建立及探討：提出域適應遷移方法解決新舊數據偏差問題，以 CNN 模型做為遷移對象微調並增加一適配層(Adaptation layer)，計算兩分佈距離，比較多項式及高斯核函數對模型穩定度與準確率的影響，後使用數據降維方法驗證遷移模型的有效性。從結果得知，所提出 GAN 模型生成的數據未包含所有訊號特徵，而數據集混入 GAN 生成的數據擴增後模型準確率提升至 99.5 %效果優異；所提出的域適應方法模型源域數據準確率達 98.6 %，目標域準確率達 94.7 %，可有效分類源域及目標域中螺桿預壓狀態。

關鍵字：生成對抗網路、深度遷移學習、域適應、滾珠螺桿、球通頻率、預壓力

Abstract

As an important component of precision machines and machin tools, it is important to monitor the preloads of ball screws, and its preload degradation or backlash exists will affect the positioning accuracy. In order to address this issue, This study propose a small sample size augmentation technique and Deep Transfer Learning (DTL) method for ball screw preload condition monitoring, the Generative Adversarial Network (GAN) model to deal with ball screw preload data shortage problem, a deep learning-based domain adaptation method to improve the pre-training model accuracy for different loading conditions of the ball screw feeding system. The scope of this study is divided into four parts－(1) Experimental planning and data collection: The ball screw feeding system is operated at constant speed, and the vibration signals of two different load are collected(30 kgw weight and ball screw load module)for three types of preload states (4%, 1% preload and 12 μm backlash), the 30 kgw weight load collects 2500 data for individual preload states and ball screw load module collects 500 data, as source domain and target domain data respectively; (2) Analysis of vibration signals: The relationship between individual preload states and ball screw vibration was investigated by spectrum and envelope analysis, analyze the characteristic frequencies and causes of vibration signals,when the preload degradation or backlash exists, in addition to the ball pass frequency caused by ball impact there are several sideband components, i.e., the amplitude modulation phenomenon caused by ball impact when the ball screw is running; (3) Data augmentation model building: To investigate the performance of the GAN framework, the model is trained using 500 datas the 30 kgw weights load of 4% ball screw preload vibration signal,and created the generated dataset.We find original the 30 kgw weights load of 4% preload vibration signal features and used to create artificial simulated signals, and then three classification models were used to compare the performance of the data augmentation method ,These models are Convolutional Neural Network (CNN), Multilayer Perceptron (MLP) and eXtreme Gradient Boosting (XGBoost); (4) Deep transfer learning model building: Propose a domain adaptation transfer method to solve the problem of old and new data bias, use the CNN model as the transfer object to fine-tune and add an adaptation layer, calculate the distance between two distributions. Compare the effects of polynomial and Gaussian kernel functions on the stability and accuracy of the model, and then the validity of the transfer learning model is verified by using the dimension reduction method. From the results, the data generated by the proposed GAN model does not contain all signal features. However, the accuracy of the model is improved to 99.5% after the dataset be augmented by blending the generated data; the accuracy of the domain adaptation method reaches 98.6% for source domain and 94.7% for target domain, which can effectively classify the ball screw preload states in the source and target domains.

Keyword：Generative Adversarial Network, Deep Transfer Learning,Domain Adaptation, Ball Screw, Ball Pass Frequency, Preload