CSE 572: Data Mining
Final Project Literature Review

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Project Title: Signal Processing Data Mining for Predictive Maintenance

Step 1: Summary of relevant work

1. *Hai Qiu, Jay Lee, Jing Lin. "Wavelet Filter-based Weak Signature Detection Method and its Application on Roller Bearing Prognostics." Journal of Sound and Vibration 289 (2006) 1066-1090*

Brief Summary:

- Introduces a wavelet-based filtering technique to enhance weak signals for early fault detection in roller bearings.
- It presents a case study where the proposed method demonstrates promising results in real-world bearing fault detection.
- The focus is on applying the method to predictive maintenance strategies for mechanical systems.

Strengths:

- The wavelet filter improves sensitivity to weak signals, enabling the detection of early-stage faults that would otherwise go unnoticed.
- The method supports predictive maintenance by providing an early warning system for bearing faults, minimizing downtime.

Limitations:

- The study primarily focuses on offline analysis, and the potential challenges of implementing the method in real-time monitoring systems are not fully addressed.
- The effectiveness of the wavelet filter can depend heavily on the selection of wavelet parameters, which might require fine-tuning.
- The wavelet-based method may require significant computational resources, especially for real-time applications.

2. *Oscar Serradilla, Ekhi Zugasti, and Urko Zurutuza. 2020. “Deep learning models for predictive maintenance: a survey, comparison, challenges and prospect”. 1, 1 (October 2020)*

Brief summary:

- Statistical and traditional machine learning techniques for PdM are reviewed, in order to gain knowledge on baseline models in which some deep learning implementations are based.
- Related reviews on DL for PdM are also analyzed, highlighting their main conclusions.
- Identifies key challenges such as data availability, model interpretability, and real-time deployment in PdM applications.

Strengths:

- Covered models such as CNNs, LTSM with CNN, RNN which are then further evaluated on the basis of anomaly detection, failure prediction, and time-to-failure estimation.

Limitations:

- The paper doesn’t provide real-time implementation challenges.
- Although the paper touches on hybrid approaches, it does not explore them in sufficient depth, particularly how they could overcome the limitations of standalone deep learning models.

3. Zhang, S., Zhang, S., Wang, B., & Habetler, T. (2020). *Deep Learning Algorithms for Bearing Fault Diagnostics – A Comprehensive Review.* TR2020-034.

Brief Summary:

- This review comprehensively explores deep learning methods for diagnosing faults in machine bearings, a critical component in industrial machinery.
- It discusses several neural network architectures, like CNNs, RNNs, and LSTMs, that are used to detect specific bearing faults based on vibration and acoustic data.
- The paper also addresses common challenges in applying deep learning to fault diagnostics, such as data preprocessing and performance evaluation.

Strengths:

- The paper provides valuable insights into using CNN and LSTM models, both of which are techniques we are considering for time-series fault diagnosis. Its analysis can help guide our model selection and tuning processes.
- It discusses various feature extraction methods that enhance model accuracy, which can be instrumental in optimizing our own feature engineering and preprocessing strategies.
- By highlighting the real-world performance of deep learning in bearing diagnostics, the paper offers practical examples that can inform our dataset preparation and evaluation methods.

Limitations:

- The review doesn't dive deeply into how interpretable these deep learning models are, which is important for industrial applications.
- While it points out challenges like limited data and imbalanced classes, it doesn't discuss specific strategies to address these issues.

4. *"Prediction of Machine Deterioration Using Vibration Based Fault Trends and Recurrent Neural Networks" - P.W.Tse Department of Manufacturing Engg. D. P. Atherton School of Engineering*

Brief Summary:

- This paper focuses on the prediction of rate of deterioration of a defective model using neural networks. It mentions that RNN has proved to be better as compared to feed-forward neural networks when detecting a fault using time series data, and Neural networks are the current choice for handling time series data (vibrations from machines) over the classical auto-regressive methods.
- Normalized Akaike Information Criterion (NAIC), residual variance, number of parameters and root mean squared error have been used as criterion to compare various models. The smaller the values the better the model.
- Some essential features that should be extracted when dealing with machine vibration data has been discussed

Strengths

- Highlights the usefulness of using RNN models when dealing with time series data as these models can learn trends and patterns based on historical data and can accurately predict fault based on the trends.Provided mathematical explanation of how to deal with time series data
- Emphasizes on using RNN models to forecast rate of deterioration of defective part in order to reduce massive downtime
- Examples showing how vibration data from machinery bearings have been handled would help us tackle with our dataset and give us an idea of which all features are important and should be considered
- The comparison and results of the classic auto-regressive models clearly supported the idea of neural networks(RNN) to be a better choice and further exploration would add value

Limitations:

- The number of parameter considered for RNN models can be high due to which the NAIC value is at times penalized is one of the limitations pointed out in this paper
- The paper also highlights that an appropriate dataset should be considered when comparing the performance of models for forecasting machine parts failure
- No details of how the RNN model was fine tuned or if there are scope of fine tuning with increasing the complexity of networks

5. *Kavana V; Neethi M. "Fault Analysis and Predictive Maintenance of Induction Motor Using Machine Learning." 2018 Third (ICEEECCOT) 14-15, December 2018*

Brief Summary:

- Presents a machine learning model for the fault detection and classification of induction motor faults by using three phase voltages and currents as inputs.
- Signal processing techniques like Fast Fourier Transform (FFT) are applied to extract relevant features from the raw data that can be used to identify potential faults.

Strengths:

- Employed ANN to classify the dataset which helped detect faulty conditions.
- The findings are highly practical for induction motors and provided scope for similar application to DC motors as well.

Limitations:

- The paper didn't cover aspects of the entire pipeline such as preprocessing, feature selection and model selection.
- The dataset in the paper has 800 points and with such a limited set employing complex models could lead to overfitting.

6. Dey, D., & Jana, R. (2022). Bearing Fault Predictive Maintenance using LSTM. *Proceedings of the 2022 3rd International Conference on Computing, Analytics, and Networks (ICAN)*, Rajpura, Punjab, India, 1-6. IEEE.

Brief Summary

- *Demonstrates the use of LSTM for predicting bearing faults on rotating machinery using NASA's IMS Bearing Dataset.*

- Compares LSTM's predictive performance to Kernel Ridge Regression, proving LSTM's accuracy in handling multivariate time-series data.
- Offers insights into condition indicators relevant for predictive maintenance.

Strengths

- Practical application for predictive maintenance, highlighting LSTM's capabilities in real-time fault prediction.
- Uses a well-established dataset (NASA IMS), ensuring reproducibility and reliability of results.
- Clearly documents data preprocessing and feature extraction steps, providing a useful framework for similar models.

Limitations

- Limited exploration of alternative deep learning models, which could broaden understanding of predictive performance.
- Does not extensively address feature engineering, which might affect adaptability to other datasets.
- Focuses primarily on predictive accuracy, with less attention given to the computational efficiency of LSTM models in real-time scenarios.

7. *T. T. Reza, M. M. Arif, and M. S. Islam. Bearing Fault Detection Using an Effective Convolutional Neural Network Architecture. In Proceedings of the 7th International Conference on Mechanical Engineering and Renewable Energy 2023 (ICMERE 2023), Chattogram, Bangladesh, November 16--18, 2023, pp*

Brief Summary

- Demonstrated a CNN-based method that detects and categorizes bearing faults without the necessity for feature extraction.
- Employed ReLU and Softmax as activation and classification functions respectively.
- Clear tabulation on the number of epochs for the two datasets was presented confirming the effectiveness of CNN.
- The dataset was split into 70,10 and 20 percentages for training, validation and testing purposes.

Strengths

- The proposed model achieved 100% accuracy in fault classification.

- By accurately detecting bearing faults, the model supports predictive maintenance supporting real time diagnosis and automatic classification.

Limitations

- The model may require retraining or fine-tuning with varying hyperparameters to fit for other datasets.
- The CNN model requires large amounts of labeled training data which might not always be available.

8. *Rehab, A., Ali, I., Gomaa, W., and Fors, M. N. 2023. Bearings Fault Detection Using Hidden Markov Models and Principal Component Analysis Enhanced Features. Production Engineering Department, Alexandria University, Alexandria, Egypt, and Department of Industrial and Manufacturing Engineering, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt.*

Brief summary:

- This study presents a new method that combines Hidden Markov Models (HMM) with Principal Component Analysis (PCA) to detect faults in bearings using vibration data.
- It shows that PCA can help extract important features from raw data, which is crucial for accurately identifying faults.
- HMM helps model the time-related patterns in vibration signals, making fault predictions more effective in real-world situations.

Strengths:

- Using PCA reduces the amount of data while keeping key information, which improves the performance of the fault detection system.
- The method is more accurate and reliable than traditional approaches, making it useful for predictive maintenance in industries.
- The research tackles challenges in real-time monitoring, showing its practical value for different types of machinery.

Limitations:

- The study doesn't fully address the challenges of using this method in real industrial settings, which could affect how practical it is.
- It relies on good-quality vibration data, so noisy or incomplete data might limit how well the model works.

- There isn’t much discussion on how the method can be adapted for different machines, which could affect its wider use.

9. *Oche A Egaji , 2 Tobore Ekwevugbe, 1 Mark Griffiths - “A Data Mining based Approach for Electric Motor Anomaly Detection Applied on Vibration Data”*

Brief summary:

- This paper focuses on the basic machine learning models such as K-Nearest-Neighbours (KNN), Support Vector Regression (SVR), and Random Forest (RF) to tackle early fault detection of industrial electrical motors (bearings) using vibration sensor data.
- The steps implemented in this research paper are: data collection, feature engineering, train/test data split, feature scaling, dimension reduction, applying machine learning models and finally model evaluation. Energy consumption and the level of vibration are the two most important fields considered to predict the fault
- The findings showed that RF performed better than the other approaches because of its improved detection time and fewer false positive numbers.

Strengths:

- Healthy machine data is easily available and thus this paper aims to adopt the anomaly detection technique which is nothing but identifying anomalies in vibration data when vibration samples are collected.
- The paper described the statistical features extracted from the vibration data and the significance of each of them with time. It discussed about 6 features extracted for earache of the four bearings
- PCA technique adopted for dimension reduction and it has been extremely crucial as 24 reduced to 1 in dimension space

Limitations:

- It is difficult to collect a lot of annotated vibration sensor data, and when using supervised learning, models must be trained for early fault identification.Simulating data to get as near to real data as feasible is one strategy covered in this study to address this issue. But when it comes to fault detection data, there are still some situations that cannot be replicated.
- The mathematics underlying the models' implementation and how each model was adjusted to produce the intended outcomes were not thoroughly covered in the paper

- Future research is required to determine how quickly the health of machine parts deteriorates over time and to record performance trends in order to obtain important information for future machine maintenance

10. *Dan Zhang , Senior Member, IEEE, Yongyi Chen , Fanghong Guo , Member, IEEE, Hamid Reza Karimi , Senior Member, IEEE, Hui Dong , and Qi Xuan , Member, IEEE - "A New Interpretable Learning Method for Fault Diagnosis of Rolling Bearings"*

Brief summary:

- This paper outlines the detailed use of CNN along with (Fuzzy-c-means)FCM and PCA for fault prediction in bearings.
- The results of this approach is compared to the other method based on EEMD and it is observed that the proposed method in this paper is more efficient as it takes less time for diagnosis and also distinguishes the fault types which have been difficult to distinguish by EEMD method

Strengths:

- Explicit description of each of the steps done along with the mathematical implications. The detailed explanation helps in understanding the working of CNNs which otherwise is considered as a "black box"
- Dropout regularization method discussed which helps in avoiding overfitting the model which is a high possibility when working with CNN models due to its complexity and large number of parameter consideration
- FCM algorithm discussed and implemented as it provides flexibility in fault type clustering as compared to k-means hard clustering algorithm

Limitations:

- There has not been any detailed description of how the vibration data have been pre-processed or transformed and which all features have been considered post feature extraction.

Step 2: Organization of relevant work

Papers discussing different Neural Network models such as RNN, CNN, ANN implemented for predictive maintenance of machines/instruments are:

1. Dan Zhang , Senior Member, IEEE, Yongyi Chen , Fanghong Guo , Member, IEEE, Hamid Reza Karimi , Senior Member, IEEE, Hui Dong , and Qi Xuan , Member, IEEE - "A New Interpretable Learning Method for Fault Diagnosis of Rolling Bearings"
2. "Prediction of Machine Deterioration Using Vibration Based Fault Trends and Recurrent Neural Networks" - P.W.Tse Department of Manufacturing Engg. D. P. Atherton School of Engineering
3. Zhang, S., Zhang, S., Wang, B., & Habetler, T. (2020). *Deep Learning Algorithms for Bearing Fault Diagnostics – A Comprehensive Review.* TR2020-034.
4. Kavana V; Neethi M. "Fault Analysis and Predictive Maintenance of Induction Motor Using Machine Learning." 2018 Third (ICEECCOT) 14-15, December 2018
5. T. T. Reza, M. M. Arif, and M. S. Islam. Bearing Fault Detection Using an Effective Convolutional Neural Network Architecture. In *Proceedings of the 7th International Conference on Mechanical Engineering and Renewable Energy 2023 (ICMERE 2023)*, Chattogram, Bangladesh, November 16--18, 2023, pp

Papers discussing classic machine Learning models implemented to evaluate the performance of each when performing predictive maintenance of machine parts:

1. Oche A Egaji , 2 Tobore Ekwevugbe, 1 Mark Griffiths - "A Data Mining based Approach for Electric Motor Anomaly Detection Applied on Vibration Data"
2. Hai Qiu, Jay Lee, Jing Lin. "Wavelet Filter-based Weak Signature Detection Method and its Application on Roller Bearing Prognostics." Journal of Sound and Vibration 289 (2006) 1066-1090

Papers conducting survey of existing works:

1. Oscar Serradilla, Ekhi Zugasti, and Urko Zurutuza. 2020. "Deep learning models for predictive maintenance: a survey, comparison, challenges and prospect". 1, 1 (October 2020)

Papers discussing LTSM:

1. Zhang, S., Zhang, S., Wang, B., & Habetler, T. (2020). *Deep Learning Algorithms for Bearing Fault Diagnostics – A Comprehensive Review.* TR2020-034.

2. Dey, D., & Jana, R. (2022). Bearing Fault Predictive Maintenance using LSTM. *Proceedings of the 2022 3rd International Conference on Computing, Analytics, and Networks (ICAN)*, Rajpura, Punjab, India, 1-6. IEEE.