OPEN ACCESS

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-6, April 2020

Performance Analysis of Classification Algorithms for Fault Diagnosis in Rotating Machines

Sumit Kumar Sar, Ramesh Kumar

Abstract: Classification of any given vibration signal as healthy or faulty can be done by employing classification algorithms available to us. Identification of a fitting classification algorithm is a task that should be done at the time of identification of the problem statement itself, such that required changes can be done in it if the need be. Hilbert Huang Transform (HHT) empowered Adaptive Neuro-Fuzzy Inference System (ANFIS) was used to obtain the most significant features of the vibration signals of both healthy and faulty rotating machines in the time and frequency domain, namely RMS velocity, Kurtosis, and Crest Factor (RKC). They were then fed to classification algorithms to classify the machines as healthy or faulty. Five machine learning techniques such as Probabilistic Neural Network (PNN), decision tree (DT), k- nearest neighbour (KNN), and Radial Basis Network (RBN) are utilized as classification algorithms. Decision Tree algorithm was found to be the optimal classification technique; overfitting was found to be a notable issue. To improve prediction, the decision tree algorithm was parallelly ensembled into Random Forest using the Bootstrap Aggregation method.

Index Terms: PNN, DT, KNN, RBN, HHT, ANFIS, Random Forest, Bootstrap Aggregation.

I. INTRODUCTION

It is very commonly found in non-linear and non-stationary rotating machines, that the rotating part is highly prone to defects. The defect may be immanent, i.e. due to waviness, surface roughness, dents, pits, etc., or misalignment along with continuous and unforgiving wear and tear. The only change in the effective methodology of identifying fault in a machine is that, the preciseness of the human senses, namely the ears, the skin/ touch, the nervous system, and the brain, is now being emulated by sensors to pick up vibration signals, transforms and neural networks to segregate significant features and classification algorithms to detect the health of the machine [1]. In earlier studies, it was derived that in the specific case of non-linear and non-stationary rotating machines, the HHT leads to more precise results as compared to the rather popular transforms such as FFT, Morlet Wavelet Transform, STFT, Discrete wavelet, Pseudo – Wigner Willie Distribution, S – transform, Sine convolution, TDSP, etc. [2]. Features of the vibration signal, obtained from the rotating machine, which have a crucial significance were selected from the plethora extracted by the transforms mentioned above. RMS velocity, Kurtosis, and Crest factor were found to be most material features [3].

Revised Manuscript Received on April 30, 2020.
***** Correspondence Author
Sumit Kumar Sar*, CSE, BIT, Durg, India. Email : sumitsar@gmail.com.
Ramesh Kumar, CSE, BIT, Durg, India. Email : rk_bitd@rediffmail.com

The output data from HHT was significantly cleaner with reference to noise in the aforementioned real-world consideration.Again, in the cited particular case, it is required that the selected classification algorithm must be capable of identifying and eliminating outlier data. Thus, the most popular and effective algorithms have been compared for applicability to the detection of faulty non-linear and non-stationary rotating machines.

The compared classification algorithms are KNN, PNN, RBN, PSO-SVM, and Decision Trees, emulated in Machine Learning systems. An analytical comparison between the above led to the conclusion that for the cited case, only Decision Trees are fitted to span the entire data set and predict the health of the machine [4-13].

The decision tree algorithm suffers from the malice of overfitting of data due to prevailing variance [14]. This leads to reduction in the accuracy of prediction of defect. this problem is overcome by BAGGING (Bootstrap Aggregation) of the intermediately formed decision trees and using Ensemble method to generate a Random Forest.

II. CLASSIFICATION ALGORITHMS

In laymen terms, an algorithm that classifies labelled data into requisite sub-classes based on predefined conditions is known as a Classifier. It is a mathematical model, that tests the available data on well-defined conditions and classifies it into a category. Classification algorithms are, thus, considered functions of "supervised machine learning" techniques.

This investigation was done for assessing the efficacy and applicability of the following classification algorithms to the cited specific case of non-linear and non-stationary rotating machines: k-NN, RBN, PNN, Decision Tree.

A. K-Nearest Neighbour (k-NN)

The simplest of all classification algorithms in statistics and machine learning, k-NN is a type of non-parametric, instance-based learning algorithm. This algorithm does not develop an ingenious model for itself, its basis is the distance between the instances of data. Variants of k-NN algorithm use Cartesian, Euclidean, Manhattan, Hamming distances for improving the result. This algorithm is robust to outlier or noisy data and thus is effective for large data sets. However, it is not cost/ time effective, as the calculation of the distance between data instances in every iteration needs utilization of larger resources [15]. MATLAB was used to emulate the algorithm.

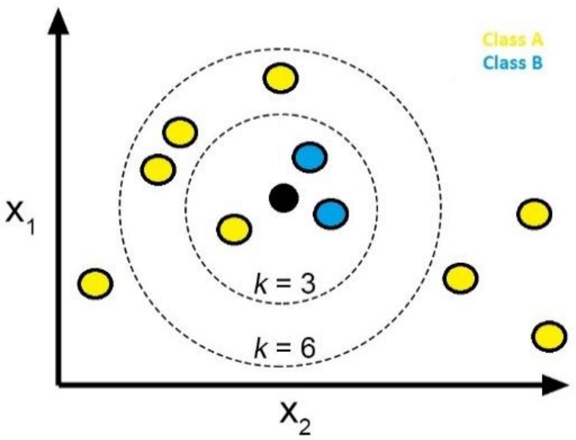

Fig 1 : k-NN Classification

$$\text{Euclidean Distance} = \sqrt{\sum_{n=1}^{t}(a_n - b_n)^2} \quad (1)$$

$$\text{Manhattan Distance} = \sum_{n=1}^{t}|a_n - b_n| \quad (2)$$

$$\text{Minkowski Distance} = \left(\sum_{n=1}^{t}(|a_n - b_n|)^p\right)^{1/p} \quad (3)$$

B. Radial Basis function Network (RBfN)

RBfN is an Artificial Neural Network and its structure may be compared to that of an MLP. Neurons of the hidden layer store a prototype to compare the incoming data, which is essentially some random data from the data set itself. The default activation function of the hidden layer of the neural network is Gaussian function: [16]

$$fn(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (4)$$

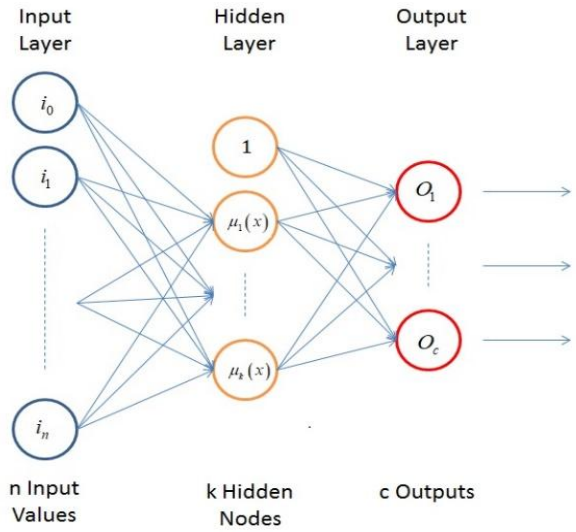

Fig 2: Radial basis function network

Where x is the input, μ is the mean, and σ is the standard deviation. The weighted sum is computed by taking activation values recalculated with feedback from each neuron of the hidden layer and the final classification depends on the highest score. RBfNs are smart algorithms that can be trained rather quickly. In this investigation, the RBFs were emulated using Matlab.

C. Probabilistic Neural Network

PNN is RBfN with a small tweak. Both have the Gaussian activation function in the hidden layers. Only the linear output layer of the RBfN is supplanted with a greedy layer in PNN which enables only one neuron to fire. All other neurons in the layer return zero. PNN algorithm is based on the concept of prior probabilities, which means, the size of classes in training data should resemble the population being modelled. Thus, the major drawback of using PNNs is the cost for the likely massive size of the hidden layer which must be identical to the size of the input vector [17]. The generalized expression for calculating the value of Parzen approximated PDF at a given point x in feature space is given as follows:

$$fn(x) = \frac{1}{(2\pi)^2 \sigma d C_A} \sum_{n=1}^{C_A} e^{-\left(\|x-k_n\|^2/2\sigma^2\right)} \quad (5)$$

Where

n = pattern number, C_A = total number of training patterns, k_n = nth training pattern from category, σ = smoothing parameter, d = dimensionality of measurement space.

D. Decision Tree

The decision tree is a supervised machine learning technique based on regression theory thus also known as Regression Tree. Decision Trees are binary trees and follow the decisions in the tree from the root node down to a leaf node to predict a response. Classification Tree gives a response such as 'True' or 'False' whereas the Regression Tree gives the numeric response. After extracting features from the raw vibration signal, the selection of a most suitable feature for bearing fault classification is itself a challenging task [18].
The CART Decision Tree is recommended in this study. The CART is a binary tree that implements a greedy approach to divide the space, which is called recursive binary splitting.
However, the recursive binary splitting procedure has to be told when to stop splitting as it generates the tree using the training data. It will determine how fitted to the training data the tree will be. Too fitted a tree will overfit the training data and is very likely to have poor performance on the test dataset. The stopping criterion is also important as it impacts the performance of the CART. Pruning techniques are used after learning by the tree to further boost the act. The number of splits in the tree is directly related to the complexity of the tree. Simpler trees are considered better as they are easy to comprehend and do not overfit the available data.

III. DATA ACQUISITION, FEATURE EXTRACTION, AND SELECTION

The vibration acoustic data set available in the IIT Kanpur data repository has been used for this investigation [19].

Significant features were extracted and the noise was removed using the EMD based HHT technique, which is the most effective method for non-linear and non-stationary rotating machines [20],[21]. The result was the final input ready to be classified.

IV. RESULTS AND DISCUSSION

A set of 225 instances for data resulted in an equal number of statistical values for each of the 3 features, namely RMS, Kurtosis and Crest factor, which were used for both training and testing purposes of four classification algorithms - k-NN, RBfn, PNN, and DT. The results of these algorithms are represented in the form of a graphs of correctly classified and incorrectly classified test samples.

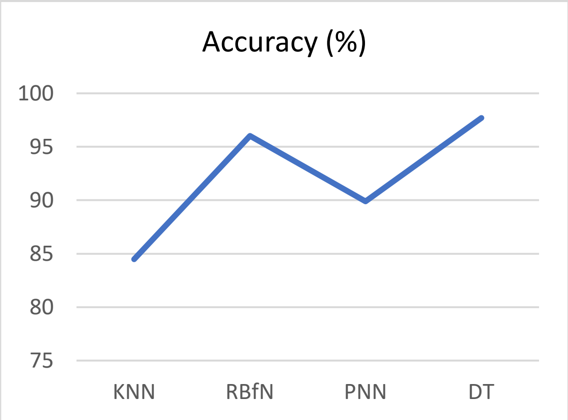

Fig 3 : Accuracy of classification Algorithms

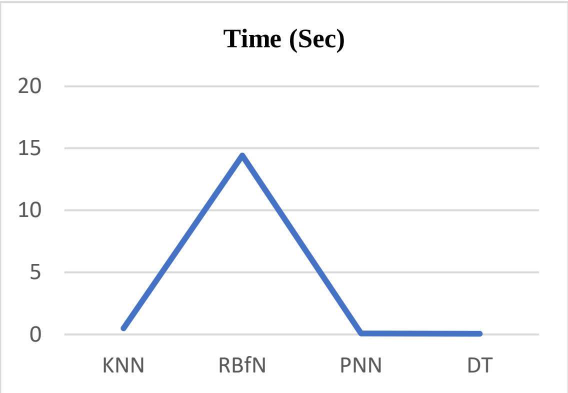

Fig 4 : Time performance of classification Algorithms

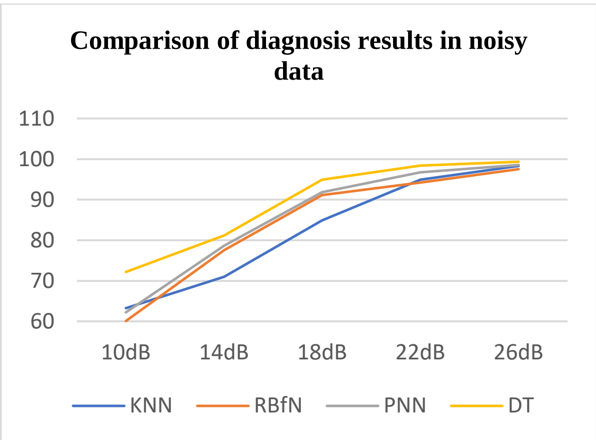

Fig 5 : Comparison of diagnosis results in noisy data by classification Algorithms

V. CONCLUSION

The experimental investigation carried out for this paper presents a comparative study of classification techniques of features of vibration signal data extracted with the help of EMD based HHT and a Neuro-Fuzzy assembly. Several rotating parts of an air compressor have been considered for the collection of data. The most significant three features of the vibration signal - RMS, Kurtosis, and Crest factor, were fed to the four most popular classification algorithms, k-NN, RBfN, PNN, and Decision Tree, as input. The aim was to identify the best applicable algorithm for non-linear and non-stationary rotating machines, where outlier data is comparatively higher. It was found that out of the four, the Decision Tree algorithm gave the highest accuracy in the least time and was more robust against outlier data for the considered data set, followed by the PNN algorithm.
Besides, this investigation does not consider the effect of an exhaustive set of bearing conditions. This method must be assessed for various bearing conditions. The future work possible in this field is the application of this method on different machines, their vibrations signatures with different bearing positions. With the development of newer and more intricate machines, the applicability of this method will gain more importance by the day.

ACKNOWLEDGEMENTS

This work is supported by Department of Computer Science and Engineering, Bhilai Institute of Technology, Durg and Dr. Ramesh Kumar. We also thank IIT Kanpur for making data sets of various machines available for research and study.

REFERENCES

1. L. Xue, N. Li, Y. Lei, and N. Li, “Incipient fault detection for rolling element bearings under varying speed conditions,” Materials, vol. 10, no. 6, 2017.
2. S. K. Sar and R. Kumar, “Signal Processing for Fault Detection in Non-Stationery and Non- Linear Machines : A Comparison”, Journal of Emerging Technologies and Innovative Research vol. 5, no. 8, 2018.
3. M. Systems, S. Maintenance, D. Vibration, E. N. Supe, L. Cedex, and R. January, “Crest Factor and Kurtosis Contributions,” Mechanical Systems and Signal Processing, vol. 11, no. 6, 1997.
4. G. Amooee, B. Minaei-Bidgoli, and M. Bagheri-Dehnavi, “A Comparison Between Data Mining Prediction Algorithms for Fault Detection (Case study: Ahanpishegan co.),” IJCSI International Journal of Computer Science Issues ISSN, vol. 8, no. 3, 2011.
5. G. Niu, J. Son, A. Widodo, and B. Yang, “Comparison of Classifiers Performance for Fault Diagnosis of Induction Motor Using Multi-sensor Signals”, SAGE Journals, vol. 6, no. 3, 2007.
6. A. Kaur and I. Kaur, “An empirical evaluation of classification algorithms for fault prediction in open source projects,” Journal of King Saud University - Computer and Information Sciences, vol. 30, no. 1, 2018.
7. P. Karimi and H. Jazayeri-Rad, “Comparing the Fault Diagnosis Performances of Single Neural Networks and Two Ensemble Neural Networks Based on the Boosting Methods,” Journal of Automation and Control, vol. 2, no. 1, 2014.
8. A. K. Srivastava, “Comparison Analysis of Machine Learning algorithms for Steel Plate Fault Detection”, International Research Journal of Engineering and Technology, Vol. 6, no. 5, May, 2019.
9. R. N. Mahanty and P. B. Dutta Gupta, “Comparison of fault classification methods based on wavelet analysis and ANN,” Electric Power Components and Systems, vol. 34, no. 1, 2006.

10. M. Jung, V. Pontevedra, M. Jung, A. Zanin, and R. Wernke, "ScienceDirect ScienceDirect Detection and Fault Isolation in Complex Systems Comparison of Different Classification Algorithms for Fault and Fault Isolation in Complex Systems Comparison of Different Algorithms for Fault November Classification Costing mo," Procedia Manufacturing, vol. 19, no. 2017, 2018.
11. S. Zhang, S. Zhang, B. Wang, and T. G. Habetler, "Machine Learning and Deep Learning Algorithms for Bearing Fault Diagnostics - A Comprehensive Review", 2019.
12. D. N. Coelho, G. A. Barreto, C. M. S. Medeiros, and J. D. A. Santos, "detection of Short Circuit Incipient Fault in a Three- Phase Induction Motor," 2014.
13. P. Agrawal and P. Jayaswal, "Selection of Best Classification Algorithm for Fault Diagnosis of Bearing using Vibration Signature Analysis," International Journal of Innovative Technology and Exploring Engineering, vol. 8, no. 5, 2019.
14. Seema, M. Rathi, and Mamta, "Decision Tree: Data Mining Techniques," International Journal of Latest Trends in Engineering and Technology (IJLTET), vol. 1, no. 3, 2012.
15. A. Moosavian, H. Ahmadi, A. Tabatabaeefar, and M. Khazaee, "Comparison of two classifiers; K-nearest neighbor and artificial neural network, for fault diagnosis on a main engine journal-bearing," Shock and Vibration, vol. 20, no. 2, 2013.
16. B. Samanta, "Networks and Genetic Algorithm," EURASIP Journal on Applied Signal Processing, 2004.
17. W. J. Wu and D. G. Huang, "Research on Fault Diagnosis for Rotating Machinery Vibration of Aero-Engine Based on Wavelet Transformation and Probabilistic Neural Network," Advanced Materials Research, vol. 295–297, 2011.
18. V. Sugumaran and K. I. Ramachandran, "Automatic rule learning using decision tree for fuzzy classifier in fault diagnosis of roller bearing," Mechanical Systems and Signal Processing, vol. 21, no. 5, 2007.
19. N. K. Verma, R. K. Sevakula, S. Dixit, and A. Salour, "Acoustic Signals for Air Compressors," IEEE Transaction on Reliability, vol. PP, no. 99, 2015.
20. J. Zhao, Y. Yang, T. Li, and W. Jin, "Foundations of Intelligent Systems," vol. 3488, 2005.

AUTHORS PROFILE

Sumit Kumar Sar received the B.Tech Degree in Computer Science & Engineering from Pt. Ravishankar Shukla University Raipur. and M. Tech. degree in Computer Technology & Application from Chhattisgarh Swami Vivekananda Technical University (CSVTU) Bhilai. He is currently pursuing Ph.D. degree in Computer Science and Engineering from CSVTU Bhilai, India. He is currently working as Associate Professor with the Department of Computer Science Engineering in Bhilai Institute of Technology, Durg. He has over 14 years of experience. He is the author of nine books including programming in C, Operating System , JAVA Programming, Unix & Shell Programming, Data Structures etc.

Dr. Ramesh Kumar received his B. Tech degree in Computer Science & Engineering, M.Tech in Computer Science & Engineering, Ph.D. in Computer Science & Engineering form CSVTU Bhilai, presently working as Professor in department of Computer Science & Engineering, in Bhilai institute of Technology, Durg, India. His areas of interests are Data Science, Data mining and Warehousing, Modelling & Simulation. He has 25 research papers published in National and International journal. He has also got an award for best paper award by IE(I) and best "Program Officer" award at CSVTU and CG State level. He is member of professional societies ISTE, IE(I), CSI, IETE, ISTD, NIPM, TSI, AIMA, ORSI, ISRS, BMESI.