International Journal of Grid and Distributed Computing
Vol. 14, No. 1, (2021), pp. 631-638

Fault Detection and Isolation in Industrial Processes Based on RNN: Deep Learning Approach

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Abstract :

Deep Learning is a subset of Machine Learning related where human brain-inspired neural network algorithms learn from a large amount of data across multiple layers for nonlinear transformation.,Deep learning domain techniques allows to extract features automatically from the Industrial fault detection dataset. Since it has the strong learning ability that can improve the utilization of the dataset for the feature extraction. It determines Industrial Processes fault in the input data by simulating the way the human brain detects the fault in the industrial processes.The Existing system automatically detects the faults and isolation based on Deep Learning. The existing system uses the process variable to prevent and detect the failures in the industrial process. Due to the process complexity and sophistication of the Industrial equipments, the existing system is not affordable and unrealistic to implement on large scale. The proposed system is based on the Parameter Optimization Techniques such as genetic algorithm (GA) and particle-swarm optimisation (PSO). These techniques are used to increase the trained model capability. So that the trained model can handle the complex correlations between the input values. To improve the prediction accuracy, the proposed system uses the recurrent neural-networks(RNN). Therefore, the proposed application predicts the future state of the industrial processes based on the previous behaviour while considering the substantial noise in the data.

*Keywords :*RNN, DAE, genetic algorithm, particle swarm optimization.

I . INTRODUCTION

In recent years there has been a growing interest in defect detection due to increased levels of automation and the increasing demand for greater efficiency, productivity, reliability and safety in industrial systems.Fault detection can be a complex reasoning operation, which is actually one of the fields in which Techniques of Artificial Intelligence has been implemented successfully, these approaches makes use of associations, reasonable thinking and decision-making process just like the human brain.

The initialway of detecting faults are focused on testing some significant measurable variables for limit value checking, lot of useful research has been done in this area. These methods lacks the ability of in depth fault detection and does not simulate the human thinking process.By avoiding potential process failures and optimizing process maintenance schedules, fault prediction has both safety and economic advantages.Isermann (1984)[1] noted that early detection of process faults is an important prerequisite for further development of automated supervision. Many fault detection methods in

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industrial processes allow identification when observable output signal limit values have already been exceeded. New methods are necessary to predict and compensate for faults. Hence, mathematical modeling methods should be added with artificial intelligence techniques resulting effective industrial fault and isolation.

Artificial Intelligence challenges human intelligence models by creating systems that can operate independently in their respective environments making use of its knowledge .As fault detection methods, there are several techniques that makes use of statistical methods ,expert systems and traditional signal limit value checking and also latest methods includes the use of neural networks. In order to have more efficient systems, emerging developments include the coupling of these applications.Zhang and Morris (1996)[2] describe the implementation of these coupled fault detection techniques as a strategic research subject due to the growing demand of industrial processes to have moresafety and also to have profited economically.According to Frank (1990) use of neural networks systems open a door for effective fault detection for complex industries processes that can lead to effective fault detection and isolation.

The existing system makes use of auto encoders as the neural network which has been used for analysis of sensor data, the identification of irregular conditions and identifies the faults. Fault occurrence can be dependent on previous activity or state, auto encoders lacks the ability to deal with special temporal data,Due to the process complexity and sophistication of the Industrial equipments, the existing system is not affordable and unrealistic to implement on large scale. The proposed system makes use of recurrent neural network in order to identify the faults in industrial process data, also we have used genetic algorithm and particle swarm optimization techniques inorder to increase model capability for accurate diagnosis of industrial faults.

The overview of this paper :

1) In this paper, we have proposed industrial fault detection based on RNN
2) Also we have used parameter optimization techniques with RNN in increase the model capability.
3) Related work section includes previous similar works in the field anomaly/fault detection in industrial processes.
4) The section of proposed system introduces you our proposed methodology of using rnn and other optimization techniques. And in evaluation section we have presented comparative results of proposed models for fault detection in industrial processes.

II. RELATED WORK

The classical method of detecting faults is to check a system's measurable variables for a certain tolerance of normal values and to cause warning signals if the tolerances are exceeded or when they reach a certain limiting value and then taking the appropriate action. Signal processing techniques employs parameter estimation and makes use of statistical techniques which are essential fault detection and isolation schemes. Diagnosis of faults by using computational mathematical models is a well known established area. Frank (1992, 1996)[3] characterizes model based analytical redundancy methods are one of the most capable among underlying strategies due to the advent of powerful mathematical modelling techniques.Faults can be identified in this case by comparing collected data by a related mathematical models. When the data is temporal and non linear, variety of approches have been suggested by the researchers, in this case measuring accurate value is very difficult and no valid mathematical model exist.

Methods that has come from artificial intelligence has allowed new approaches for the detection of faults in dynamic systems. In the late 1960's and early 1970's, expert systems were developed as a subset of the artificial intelligence branch. In the 1980s expert systems came out of labs and

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developed commercial applications due to the strong new technologies for professional device manufacturing and new hardware choices. E.Feigenbaum (1982)[4] defined expert system as "A smart computer program using expert knowledge or procedure to resolve issues that are difficult to achieve, requires significant human expertise to solve". Facts like: An expert approach simulates the thinking of people about a problem area, as the main focus is on the problem-solving expertise of the expert and on how relevant tasks can be done. A system of experts often conducts numerical calculations or the retrieval of data using the information base and the inferential engine individually. Instead of directly constructing relationships, an expert method addressing issues with heuristic knowledge adequately represents the nature of most human knowledge coping with symbolic values and processes. Fault detection is one of the main fields in which early use of expert systems is found.

In the early 1970s, the first expert system for technical fault diagnosis has been developed byScherer W. and C. White (1989)[5]. Since then several systems has been developed. Initially diagnostic expert systems makes use of rules and reasoning got by the observation, while functional reasoning is used by new model-based expert systems. In the form of production rules, information based on rules-based structures is expressed. The empirical correlation between premises and assumptions in the knowledge base is their main characteristic to define logical event chains which can represents the spread of complex phenomena, these associations explain cause-effect relationships. Effective fault detection procedures can be driven by heuristic-based expert systems, but they lack generality. The limitations of the early diagnostic expert systems were considered by Widman et al (1989) [6] as:1.Capacity to accurately reflect different phenomena of time and space. 2. The program's failure to identify clear knowledge base gaps. 3.Knowledge engineers have trouble gaining knowledge effectively from experts. 4.Difficulty in maintaining continuity in the knowledge base for knowledge engineers. 5. The programme's failure to learn from its mistakes.A number of shortcomings in the rule-based approach are found, including a lack of generalization and a bad handling of new circumstances.

By using model-based approaches, the key drawbacks of the early expert systems can be overcome. Expert information is mainly found in an expert domain model. For simulation, those models can be used for hypothetical issues. Model-based detection uses form, feature and behaviour information and provides independent diagnostic procedures for devices. In detecting faults, these systems provide greater robustness since they can deal with unpredictable situationswhich are protected by heuristic laws. The basic knowledge of these systems is less expensive to create because its design requires no expertise. Furthermore, in the case of design changes, they are more versatile.Model-based diagnostic systems provide versatility and consistency, but also rely on the domain. Due to their primary ability to discern patterns, neural networks find application in fault detection.

neural network will be trained with data so that It can learn to build an internal representation of the issue from the presentation of examples.Also It is important to link the sensor measurements to the reason of faults and differentiate between normal working condition and abnormal working condition for fault identification. The current method uses auto encoders as the neural network, adds input vectors to the neural network, and changes the link weights to accomplish particular objectives. A neural network algorithmchanges weightings of inputs automatically which decreases the average square between the actual output value and the expected output value. An essential feature of neural networks is that there is no need for good models to make a decision. The neural network process model can approximate functional relations that describe the process andit can be mapped internally by the neural networks. There is no need for the creation of complex rules or algorithms compared to other systems.

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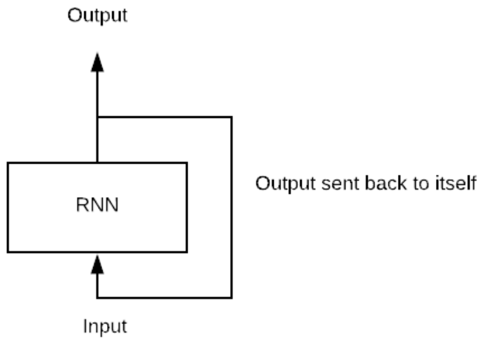
III. PROPOSED SYSTEM

The principle of recurrent neural networks (RNN) is used in the proposed framework. It makes use of sequential informationfor better accurate results.In a simple neural network, we assume that all inputs and outputs are independent, But what if you know what words came before? it would be more helpful to estimate the next word.RNNs are referred to as repetitive, for each element of the series, they perform the same procedure with an output dependent on previous calculations. This knowledge about what has been measured so far is another way of thinking about RNNs.In arbitrarily long sequences, RNNs may theoretically use data, but they only look back a few moves in practice.This is how a regular RNN looks like:



great success has been shown by recurrent neural networks in NLP tasks, forecasting stock values, self-employed vehicles, text analysis, image captioning, emotion analysis and machine translation, etc.LSTMs are the most frequently used type of RNNs. Under the hood it has the similar architecture like RNNs, but they makes use of different function inorder to calculate the hidden states of the network.Memory in general is termed as cells in LSTMs, and you can think of them as cell that takes the previous state value and current input values andthen collectively determine what should be store and what should be deleted from the cells. The previous state value, the current state value, and input are then combined and turns out capturing long-term dependencies, these types of units are very successful. The architecture of the system is as in fig(1).

We also applied parameter optimization methods like genetic algorithm, particle swarm optimization techniques with rnn to increase the trained model capability. The genetic algorithm belongs to a class of evolutionary algorithms inspired by biological evolution in general. We all know that biological evolution is a selection of parents, reproduction, and offspring mutation.The primary goal of evolution is to reproduce offspring that are greater biologically than their parents.

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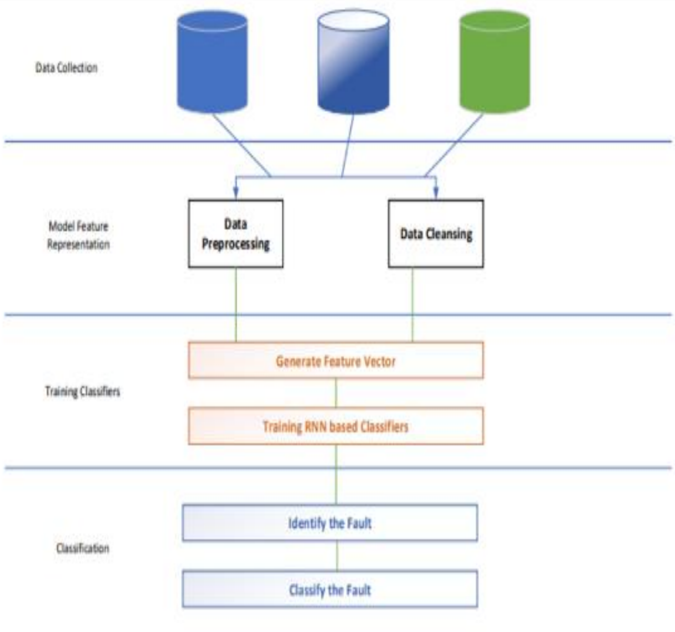

fig(1)

A hereditary by Natural Selection in Evolution, and it seeks to simulate the same. The fundamental intuition is to choose the best individuals from the population as parents, asking them to prolong their generation by reproducing and getting their children during the process of reproduction where an error known as mutation occurs.Once again, these children are asked to replicate their children, and the process continues, leading to healthier generations.

Genetic Algorithm pseudo code:

```
prepare initial population
randomly initialize population
    repeat
        estimate the objective function
discoverthe fitness function
        apply genetic operations
            reproduction
            crossover
            mutation
     until we met stopping criteria
```

Anotherwell known optimization techniqueparticle swarm optimization (PSO) is population based stochastic optimization method which was, introduced by Dr. Eberhart and Dr. Kennedy, in 1995. The algorithm has got inspired from natural phenomena like bird flocking or fish schooling behaviour. The particle swarm optimisation technique simulates bird flocking behaviour. imagine a group of birds which looking for the food in a certain region,in thatsearch area there is only one place where food is located. Every bird is not aware of where the food is actually located. But they know how far the food is in each iteration. Hence, best strategy would be to follow the bird that is closest to the food.Swarm intelligence learns from the thisprospective and uses it to solve the problems of optimisation. In particle swarm optimization, each single solution is a assumed as bird and We call bird as particle.Every particlewill have its individual fitness values that are measured and then optimized by the fitness function and have speeds that direct the particles to fly. By following the current optimal particles that

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fly through the problem space we will be able to get to optimum global parameters, resulting in the model's strong predicting performance.

PSO Algorithm:

Step 1: estimate the fitness value of each particle

*Step 2:*Update global and individual best fitnesses and positions values

*step 3:*Update position and velocity of each particle

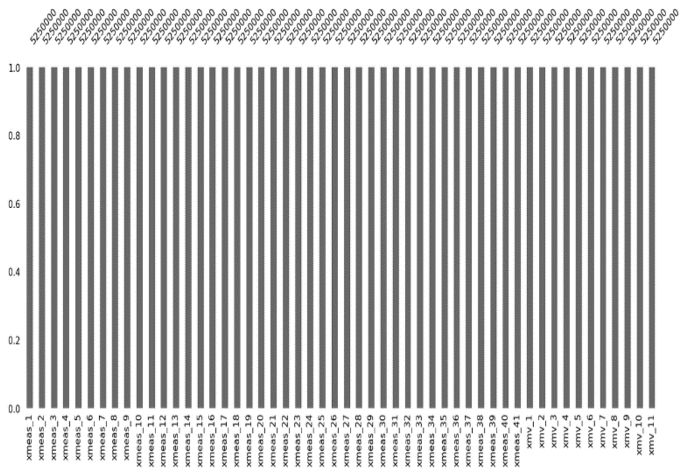
IV . Evaluation

Dataset:

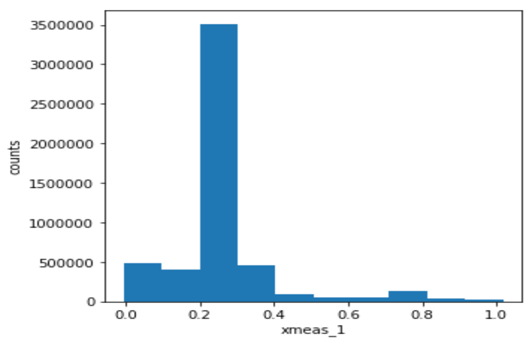
The dataset that we have used was Tennessee Eastman Process Simulation Data for fault Detection referenced by Rieth et al. (2017)[7]for Joint Human-Automated Systems. Dataset is takenfrom website https://dataverse.harvard.edu/ dataset contains 52 process variables which are observed continuously and classified into 1-20 faults types.

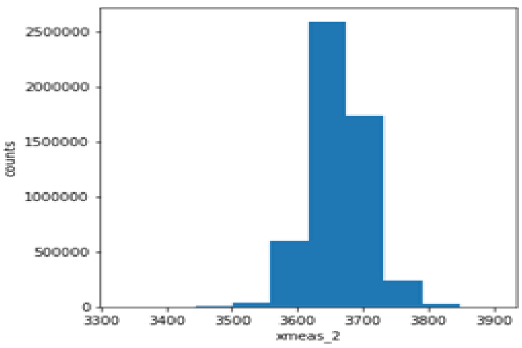
Exploratory Data Analysis:

After loading dataset we checked if the datasets are having any null values. We used missingno library to check for missing values for each column.



From the above plot we can observe that there are no missing values in the data that we have used, also we have plotted the distribution of each of the 52 features of the train data like below





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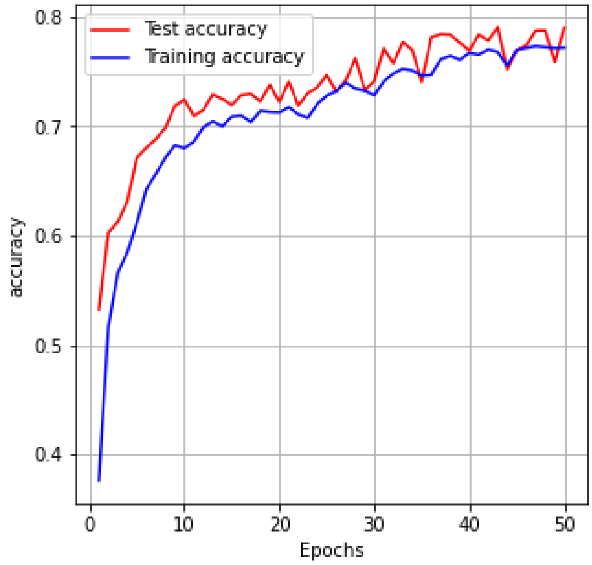
We have applied auto encoder, rnn , rnn with genetic algorithm,rnn with particle swarm optimization, the model evaluation graph is below.



The accuracy comparision for different neural network models is as below

MODEL	ACCURACY
DAE	0.66
RNN	0.77
RNN + GA	0.99
RNN + PSO	1.0

We can observe that the recurrent neural network outperforms the autoencoders when combined with parameter optimization techniques like GA and PSO in terms of the accurate prediction of the faults.

V. CONCLUSION

Quality assurance and fault detection is the important aspect that should be taken care in the modern industrial processes, inspite of having control over the processes in industries we cannot assure quality of the product, a small malfunction can cause the tremendous amountof loses and hence there is a need of automated industrial fault detection and isolation techniques in order to identify the faults that has been occurring in the modern industries so that we can rectify the issues on-time.This paper introduced a deep-learning approach to FDI that is capable of processing highly complex manufacturing data. The proposed approach is capable of modeling spatial-temporal data from the industrial manufacturing processes which will have complex correlations among them and been able to predict the faults with high accuracy. Results prove that the proposedsystem is capable of outperformingother FDI technique both in terms of accuracy and also in the range of faults that it can detect.

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