Condition Monitoring and Predictive Maintenance of Industrial IoT Systems using Fog Computing

Malarvizhi D, S Padmavathi

Department of Information Technology, Thiagarajar College of Engineering, Madurai, India

Corresponding author: Malarvizhi D, Email: malardevadas@gmail.com

Condition Monitoring and Predictive Maintenance are emerging in the Industrial environments for effective maintenance of the assets and the machinery. This involves monitoring the equipment in an effective way to prevent unexpected failures and unplanned downtimes in the production environment. The scope of this work is to provide high level details on Condition Monitoring which in turn is used for Predictive Maintenance. This paper proposes a novel infrastructure to use the Fog computing layer in industrial environments, in order to prevent failures before they happen, allowing seamless monitoring of the production environment and thus preventing catastrophic system failures in advance.

Keywords: Condition Monitoring, Predictive Maintenance, Fog Computing, Internet of Things (IoT).

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1 Introduction

Condition monitoring (CM) refers to the process where a specific condition of machinery is monitored to identify possibilities of a developing fault in an industrial environment. It helps in predictive maintenance of the industry as this allows early planning for scheduling maintenance and to take preventive actions to prevent further failure of the machinery due to wear and tear and unplanned downtime.

Condition Monitoring was originally done by manual inspection, continuously monitoring the behavior and condition of the machinery and confirm the proper functioning of the system. With the advent of modern technologies, advanced maintenance techniques can be deployed to have real time monitoring and schedule planned maintenance. Without condition monitoring in place, the system would have to run until it fails and then planned for replacement as a whole or its components.

With the advent of Internet of Things (IoT), devices across the globe are connected almost all the time. The IoT communication is majorly dependent on the communication across systems that are equipped with IoT sensors. In Machine to Machine Communication (M2M), machines can communicate with each other without or minimal human intervention [1]. Internet of Things offer a wide range of solutions enabling machines/devices to talk to one another and are trained to make intelligent decisions as and when needed. An IoT application acts on the large volume of data that are generated by the Edge nodes. The data is then analyzed and processed further to make decisions based on the inferences and trained models. With IoT, the major processing happens at the Cloud due to the higher processing capabilities in addition to the huge amount of data storage capabilities.

Machinery in an industrial environment can be embedded with IoT devices to work in synchronization and can be analogous to the IoT Edge nodes talking to each other. The devices can fit in IoT architecture with the data processing happening at the cloud. Considering the cost involved in safety and maintenance, the environment will require faster responses to prevent additional costs incurred in repair of the system.

Fog computing is an additional layer that sits in between the Cloud and the Edge device to enable faster processing and make quicker decisions with the real time data [2]. Fog computing offers a variety of benefits compared to Cloud computing in terms of real time data processing. This can also aid in conserving network bandwidth.

The paper is organized as follows. Section II discusses the related work. Section III presents an overview of condition monitoring & predictive maintenance and its challenges in industrial environment. Section IV discusses the background of IoT and Fog Computing. Section V briefs the proposed architecture and the simulation environment used. Section VI presents the results and analysis based on the dataset used. Section VII concludes the paper.

2 Related Work

IoT is a rapidly expanding field with computing capacity along with capability to connect between devices. Industrial IoT and Industry 4.0 [3] have seen a tremendous growth due to the involvement of IoT devices and sensors. For the condition monitoring and predictive maintenance, the system must ensure avoidance of noise and fault. Multiple applications of IoT involves Industry 4.0 [4] [5], smart energy [6] [7], smart city and buildings [8] [9] and so on. The process of identifying patterns that do not conform to the expected behavior of the system refers to Anomaly detection [3]. Various elements of IoT data makes the interpretation of anomaly detection challenging such as dimensionality of IoT data, noise present in the IoT data and the stationarity of the IoT data. Anomaly detection in time series IoT data is complex in terms of latency and network consumption. This paper tries to overcome that issue by deploying the fog layer for processing.

Anomaly detection has been always a broad research field in fault detection [10][11]. Anomaly detection in Industrial IoT use cases is significant as it can identify potential fault in certain components. A big data ecosystem is presented in [12] for fault detection in Industrial IoT smart manufacturing, where data quality issue is manually solved using threshold. A sliding window technique is used in [13] along with the statistical techniques to define the analysis unit of contrast measure. Machine learning based techniques are also used in [14] to normalize the behavior of anomaly detection and it has been applied on sensor data. To compute the noise score, this approach measures both the rate of change and deviation by which the anomalies can be preserved in IIoT data especially time-series. Majority of the work in anomaly detection does not distinguish noise detection which is one of the main issues [15]. The noise in IIoT sensors is another important aspect as it affects the overall performance of the system. A lot of research focusses on the IIoT data cleansing [16] [17] [18] through many techniques, however, the existing IIoT works still lacks in potential predictive maintenance and condition monitoring. Hence this paper proposes system to utilize the fog layer for efficient monitoring and maintenance of IIoT systems.

Fog layer is the intermediate layer present between the edge, where the data is actually generated and the cloud, where the data is processed for operation. In Industrial IoT, the data generation happens often through the smart objects and sensors. This paper imposes the potential of fog layer as majority of the IIoT use cases deal with sensor data that need immediate attention. Anomaly detection requires significant methods to process data from IIoT sensors and interprets their results. Deployment of fog in IoT network adopts three-layer architecture as shown in figure 1. Fog based methods [19] [20] uses machine learning and statistical methods to detect anomalies. These methods scan the traffic to identify the abnormalities. Semi supervised learning-based techniques is also used in fog for anomaly detection.

3 Condition Monitoring and Predictive Maintenance

Condition Monitoring (CM) can be deployed in a wide range of applications across industries that involve machinery or equipment put in use. CM can be used to have a sanity check on the efficient and safe running of machinery that can help in preventing failures and the unplanned downtimes which possibly lead to replacement or repair.

CM techniques are used on different types of equipment that includes auxiliary systems, rotating machinery and machinery parts such as pumps, motors, compressors and presses. CM can also be deployed in a wide range of application areas not limited to railways, marine environment, aircrafts, wind turbines and power generation environments.

Traditional condition monitoring majorly relied upon vibration analysis. With the advent of modern and innovative techniques sensors are used to measure various parameters in real time and can be enabled to send alerts from the system whenever an abnormality is detected. Advanced condition monitoring techniques can prevent the system from failing and planning the maintenance in advance. This helps in improving the efficiency and prevents unexpected downtimes of the system.

Deployment of Condition monitoring can be done in three steps which are detailed below:

(i) Installation of Monitoring System

Installation of the monitoring system hardware onto the serviceable equipment is the first step in condition monitoring.

(ii) Measurement of Baseline Data

Performance of the equipment can be measured with the monitoring system installed. The collected data can include multiple parameters such as rotor speed, vibration, and temperature and process sensor data. This will give a baseline against which the equipment can be monitored with reference to the optimum operating conditions.

(iii) Ongoing Monitoring

The system now monitors the environment using condition monitoring software that in turn rely on the sensors for evaluating the performance of the system and provide diagnostics. The system can then be enabled to send alerts upon detection of an abnormality in the operation of the machinery. The data can then be assessed to determine if any immediate action need to be taken or if the machine can continue to operate for a longer period until maintenance is planned.

CM offers a lot of benefits in terms of scheduling maintenance, safety and operation costs, safety and reduced downtime. It also helps in improving the efficiency of the assets, thus improving the Return of Investment (ROI).

4 Industrial IoT and Fog Computing

The Internet of things (IoT) describes the network of objects that are connected over the Internet. The objects could be retrofitted or modified with sensors, software, and other technologies that enable them to connect and exchange data with other systems on the Internet. The devices that are used to generate the source of data are the Edge nodes and the data from multiple Edge nodes are processed at the Cloud. Cloud computing can be used to extract intelligence from the data received or perform tasks that are not possible at the Edge devices. Fog computing is a new paradigm, which enables extending the standard cloud computing capabilities to the edge. Therefore, it is also called Edge Computing. It is responsible for providing computation, storage, and networking services between the end nodes in an IoT and traditional clouds. Fig 1 shows the three-layer IoT architectural model involving Fog as an intermediate processing node in Industrial IoT environment.

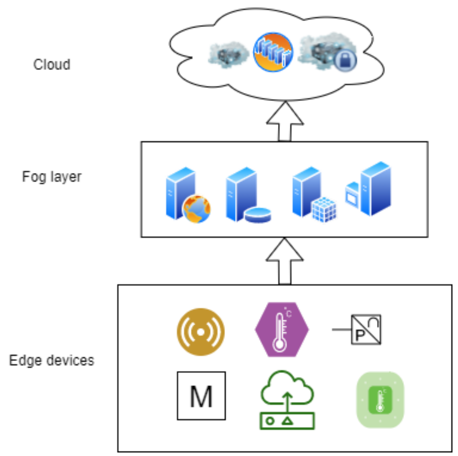

Fig. 1. IIoT with Fog Computing

The Internet of Things (IoT) can be deployed to condition monitoring of industrial environments as the equipments are enabled to connect and communicate with each other. This means that the smart machines that are located in different geographical locations can connect and communicate with each other to provide a combined comparison between systems.

This additional data will help to make proactive decisions about the machinery and any maintenance requirements. It can also improve efficiency of the machinery as the time it takes to carry out monitoring on one machine can be used to test and analyse multiple machines simultaneously.

Connected machines can also be used for comparable data analysis of an entire production process regardless of location and usage of the machines. Once an abnormality in the running levels of the machinery is detected across the chain of production, this can be used by the operators to assess the suspicious root cause of the problems and act on the imminent faults.

Different types of monitoring techniques can be used to assess the condition of the equipment. These include monitoring using sensors in addition to more physical techniques. Different methods may indicate the same fault, and they can be combinedly used to deliver an overall picture of the health of the equipment. Each type of condition monitoring can make use of a range of different techniques to achieve them.

Condition monitoring systems provide several benefits in terms of financial, operational, and safety perspective of industries. When used with connected systems over the Internet, condition monitoring allows users to utilize the best of planned maintenance downtime to service multiple machines and address multiple problems at the same time.

5 Proposed Architectural Framework

Condition Monitoring and Predictive Maintenance systems in industries are equipped with a lot of smart sensors which are constantly sensing and collecting information about the environment to provide a detailed picture of what is happening around. This in turn leads to generation of voluminous data that needs a high processing device to provide insights of the environment. The smart sensors can be directly connected to the cloud and the data from these sensors can then be processed at a Cloud device for real time inferences and provide effective data on the maintenance of the ecosystem. The real time data collected from these smart sensors can be processed and computed at the Cloud devices to predict and detect the deterioration and replacement of the machines. The prediction from the cloud can be used to take necessary immediate corrective actions to prevent damages and failures. Long term analysis on this data can be also be used for analytics on the processed data, collected from multiple sensor sources.

Considering the expected latency of the processing, sending the data to cloud for the prediction analysis can take a toll on the machine maintenance and results in unexpected failures and downtimes. Transferring of the data from the sensors directly to the cloud also consumes more network bandwidth. In order to save power consumption and to maintain the confidentiality of the data, a Fog device can act as an intermediate to do the processing for faster responses and bandwidth conservation. The fog device can run the prediction algorithms and report failures faster to take up corrective actions at the right time. The data can still be processed at the cloud for long term analytics.

The proposed work uses a Cloud platform for simulation of IoT Hub and devices. Smart sensors created in this case are considered as IoT Edge devices and mapped to the IoT Hub created. The sensors send data to the Cloud which in turn are processed to detect anomalies and used for predictive maintenance using Machine learning algorithms. This incurs cost and delay to the industries which rely on the data from the cloud for the monitoring of the industry system and plan for maintenance.

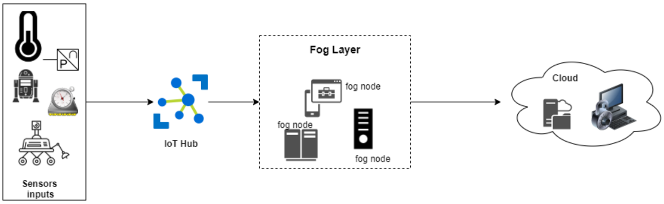

Fig. 2. Proposed Architecture for Condition Monitoring

Deploying a Fog node as an intermediate layer between the cloud and sensor nodes enables faster processing and in turn helps detect anomalies and better maintenance. The processed data can be sent back to the cloud with the prediction analysis from the Fog node. The Fog node is simulated to detect anomalies before the data is sent to the cloud and send alerts to plan for maintenance. Addition of fog node as an intermediary in the processing aids in improving latency of the overall system.

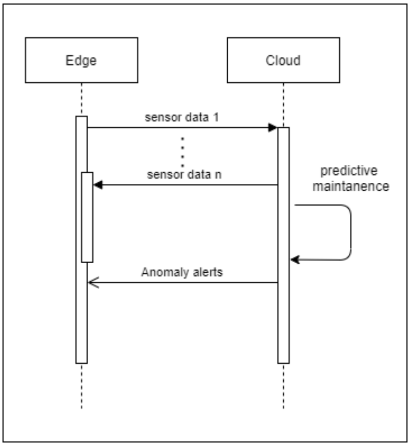

Fig. 3. Condition Monitoring & Predictive Maintenance with Cloud Computing

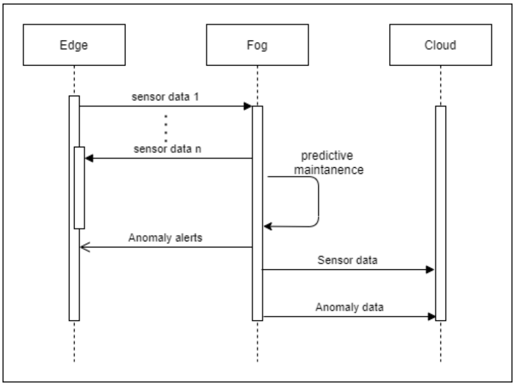

Fig. 4. Condition Monitoring & Predictive Maintenance with Fog Computing

6 Results and Discussions

The proposed framework is simulated using Open Cloud platform from Mathworks and test data for condition monitoring is fed into the system. The simulated test data uses information from three different sensors – Temperature, Pressure and Humidity inside a machinery cabinet. The dataset is simulated to be processed for maintenance alerts in two different setups – Cloud and Fog. The analysis from the Cloud and Fog setups are depicted in Fig 5 and Fig 6.

Fig 5 shows the plots for the data from different sensors used. As observed from the charts, it is inferred that there is a greater dependency on the cloud to extract necessary information from the input dataset. Cloud computing is essential to gather information on the maintenance schedules or the system failures. This also impacts the system performance due to the voluminous nature of the processed data.

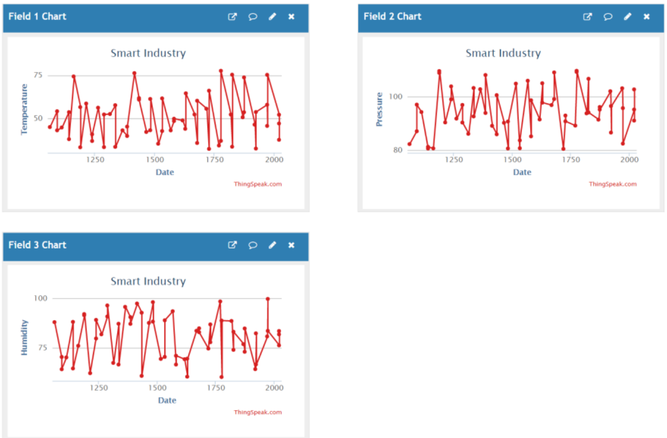

Fig. 5. Plots from Input data without Fog Computing

Fig. 6. Plots from Input data with Fog Computing

Fig 6 shows the plots of the dataset received from the sensors and there is an additional intelligence from the Fog system that sits in between the Edge devices and the Cloud to run a Machine Learning algorithm to detect the anomalies. The system is assumed to monitor the dataset when the input data from the sensors exceed a threshold defined for each of the sensor data and report as an anomaly if any discrepancy is found. This in turn can be reported directly to the Edge devices through an alert management system. This results in quicker and efficient actions in addressing any change in the machine behavior and taking preventive or corrective actions as necessary.

7 Conclusion

Fog computing offers several advantages over Cloud computing in terms of latency and performance. However, Fog computing cannot completely replace Cloud processing, as it has limitations in terms of the high computational and storage capabilities. Condition monitoring is becoming common across industry as a method to ensure the safe working of assets and work environment and to improve efficiencies. Allowing for scheduled and directed maintenance eliminates unnecessary procedures that can save both time and money, besides ensuring production schedules are met. This paper proposes a methodology for integrating Fog computing with Condition Monitoring for Predictive maintenance. This could also aid in the effective maintenance of industrial environment and enable them to operate with minimal or no human intervention. The proposed approach can be expanded in the future to incorporate more intelligence based on the environment in which the Condition monitoring is supposed to be deployed.

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