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Internet of Things (IoT) Applied to Rotor Fault Diagnosis in Electrical Machines at Remote Sites

Nicolly Menezes Bastos, Raphael André Medina, Da Costa Cesar*

IFSP - Institute Federal of Sao Paulo, Department Electrical, São Paulo, SP, Brazil
*Email: ccosta@ifsp.edu, br

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***Abstract*— *The Internet of Things (IoT) describes the network of physical objects embedded with sensors, software and other technologies with the aim of connecting and exchanging data with other devices and systems over the Internet. Therefore, this work aims to develop a system (hardware and software) that allows the interconnection of remote electrical machines to maintenance centers, via the Internet, for the diagnosis of rotor unbalance faults, in real time, through smart sensors, cloud computing and big data.*

I. INTRODUCTION

Currently, the 4th Industrial Revolution, with the automation and digitalization of manufacturing, is awakening a new, widely connected and shared world [1]. Thus, society is experiencing a comprehensive, rapid and impactful transformation in the way it produces, manages and regulates this new economy that is emerging. Collaborative applications, smart manufacturing, the Internet of Things, augmented reality, big data, among others, are technologies and concepts that are changing the way companies produce, sell and define the profile of their specialists so that it is possible to face this revolution and achieve business sustainability [2]. Industry 4.0 is based on connecting cyber-physical systems to databases stored in cloud computing, enabling the acquisition of this data in real time by production system management programs [3]. Industry 4.0 aims to introduce new IT (Information Technology) technologies into industrial automation (factory floor), creating smart networks of products and services called the Internet of Things (IoT) [4], aiming to integrate consumers with manufacturers, optimizing the entire production chain. In this context, electrical machines such as turbogenerators, wind generators, etc., are often installed in remote locations that are difficult to access. Maintenance of these electrical machines becomes increasingly difficult and expensive due to the physical distance between this equipment and maintenance centers. IoT applications use machine learning algorithms to analyze large amounts of data from sensors connected to electrical machines and send it to the cloud. Using Human Machine Interfaces (HMI) and real-time IoT alerts, visibility into key performance indicators, mean time between failure statistics, and other information is gained. These algorithms can identify anomalies in remote electrical machines and send alerts to Maintenance Centers and even trigger automated corrections or proactive measures. With cloud-based IoT applications, enterprise users can quickly improve predictive maintenance processes for remote equipment [5].

Liew et al [6] introduced a system where they described an IoT application and ESP 8266 to track, take data, and determine issues in wind turbines. This permits the user to manage the whole framework remotely through a protected web-connected internet. This framework assists end-users to control energy sources, physically and remotely just by simply using smartphones or PCs. IoT-based remote monitoring and operations of a multiphase induction motor's many adjustable operating parameters discussed in [7]. In a short circuit motor, the sensor and sensor module monitor and report temperature, current, and voltage to the processing unit. Noyjeen et al [8] presents IoT technology temperature, voltage, vibration, and current. The software can show this data on a smartphone, access it through websites, and save it in the cloud. In order to ensure reliability in the operation of motors, advanced technologies should be employed. So that fault protection and motor monitoring can be done automatically. Using Internet of things, the monitoring of the electrical machines can be viewed from the remote areas [9].

In this paper, a case study of Internet of things (IoT) applied to rotor fault diagnosis in electrical machines at remote sites is shown. The goal is to share the experience the development of a system (hardware and software) that allows the interconnection of remote electrical machines to maintenance centers via the Internet, for real-time fault diagnosis, through smart sensors, cloud computing and big data. The paper is structured as follows: Section II discusses the background topics that have been involved in. Section III, methodology used in the implementation, and Section IV concludes the paper.

II. BACKGROUND

Rotor imbalance is the most common cause of vibration in electrical machines. In practice, rotors can never be perfectly balanced due to manufacturing errors such as casting porosity, non-uniform material density, manufacturing tolerances and material gain or loss during operation. Mass imbalance leads to the generation of a centrifugal force and must be neutralized. Vibration analysis is extremely important for monitoring faults in rotating machines and making an associated diagnosis for repair. The development of experimental procedures based on the implementation of instrumentation systems and computational tools applied to the treatment and monitoring of dynamic quantities that describe the behavior of machines under operating conditions are of fundamental importance in the design and maintenance of electrical machines. Every rotating machine can be basically formed by three components: the rotor, the bearings and the support or foundation. A model used to this day, with a flexible shaft, supported by rigid bearings, with an unbalanced disc in its center, shows the emergence of critical speeds. This rotor model, called the Jeffcott rotor, explains how the amplitude becomes maximum at the critical speed and why the unbalanced mass moves internally in the rotor orbit [10]. The Jeffcott rotor consists of a shaft, a disk, and a mass imbalance. Fig. 1 shows a simplified model of a rotor.

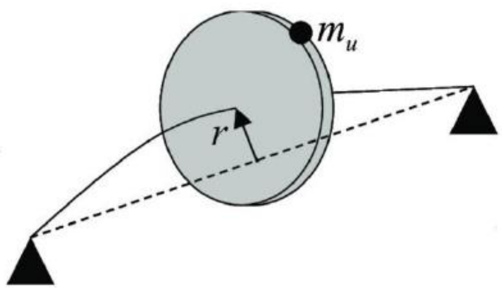

Fig. 1: Simplified representation of a rotor [10].

Vibration analysis (or vibration monitoring) is a powerful diagnostic tool for identifying, monitoring, and preventing faults in rotating electrical machines shaft. It is an essential component of predictive maintenance programs, allowing technicians to detect developing equipment problems before they lead to unplanned, costly downtime or catastrophic failures [11], [12]. Vibration analysis is a component of electrical machine condition monitoring systems, using vibration sensors to measure frequencies in an electrical machine and detect abnormalities that may indicate a problem. Basically, vibration analysis is the study of the oscillatory movements of machines and their components around an established equilibrium point. These oscillations can result from several problems, including unbalances, misalignments, clearances, bent shafts, and bearing defects, among others.

Equation 1 shows how to calculate RMS. It shows the total energy content of the vibration, allowing for an overall analysis of vibration over a period of the time. This measurement is crucial for understanding the overall health of the machine, as it considers time and all previous data points [13].

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} X_i^2} \qquad (1)$$

Where:

N is the total number of readings.

X is each individual data point.

Equation 2 shows the crest factor. It is the ratio of the peak values to the mean value of the vibration wave. The crest factor can be calculated for velocity, acceleration, or any other parameter that can have both a peak and an RMS value [13].

$$Crest\ Factor = \frac{X_{peak}}{X_{RMS}} \qquad (2)$$

Equation 3 shows the Kurtosis. It gives a measurement of the spiked data, compared to the other normally operating data points. The normal value for kurtosis is three. Anything below or above that value is beyond the typical range. This measurement can be used to determine if the system being measured is about fatigue in some way, or to recognize how quickly the known fatigue is progressing [13].

$$Kurtosis = \frac{\sum(X_i - X_{mean})^4}{N\sigma^4} \quad (3)$$

Where:

N represents the total number of readings.

σ is the standard deviation.

Equation 4 shows Skewness. It measures the asymmetry in the data set. Data sets can have large or small skew values. Kurtosis and skewness often work together to show the vertical and horizontal pull of data points. These relationships are best visualized graphically in the context of this vibrational analysis [13].

$$Skewness = \frac{\sum_i^N (X_i - X_{mean})^3}{(N-1)\sigma^3} \quad (4)$$

III. LORA WAN NETWORK IN IoT

Lora WAN is an essential technology in the Industrial Internet of Things (IIoT), getting significant industry attention due to its long-range communication capabilities, energy efficiency, ease of implementation, and cost-effective infrastructure [14]. LoRa WAN operates at the physical layer of the communication network as a wireless communication technology [15]. It is utilizing Chirp Spread Spectrum (CSS) modulation to facilitate long-distance communication with minimal interference. CSS modulation is a type of spread spectrum modulation that spreads the transmission over a wide frequency range. These features enable LoRa to function effectively in dense and high-interference environments. This is particularly advantageous in industrial settings, where walls, machinery, and electromagnetic interference can obstruct wireless communication. In rural areas, LoRa can transmit data up to 15 km, while in urban environments, it covers several kilometers [16].

LoRa WAN is a protocol that operates at the network or linkage layer, bridging sensor devices and networks. It utilizes unlicensed ISM (Industrial, Scientific, and Medical) frequency bands, allowing for low-cost deployment across various industries without the need for expensive licenses [15]. The LoRa WAN protocol manages network access, data transmission, and device synchronization. It can support extensive networks with thousands of devices, making it suitable for dense IIoT applications that require scalability often. The Industrial Internet of Things (IIoT) presents significant opportunities for enhancing industrial processes through real-time data collection, monitoring, and control [16]. Fig. 2 illustrates the general architecture of integration of such LoRa WAN in industrial environments.

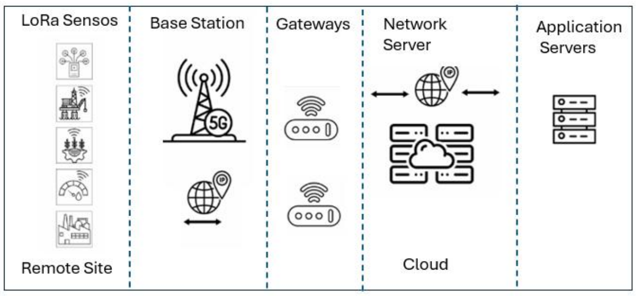

Fig. 2: Architecture of LoRa WAN in smart industries [16].

IV. LORA SMART SENSORS

WISE-2410 is a LoRa WAN wireless condition monitoring sensor integrated with an ARM Cortex-M4 processor, LoRa transceiver, 3-axis accelerometer and temperature sensor [17]. It balances the wireless bandwidth between WISE-2410 and the gateway, so it also mitigates the data transmission fail rates between edge-devices and gateways. The WISE-2410 sensor, rated IP66 for hazardous environments, is mounted on electrical machinery to monitor operational status by cross-referencing RMS velocities and eigenvalues with ISO 10816-3 vibration standards. The WISE- 6610 V2 gateway supports Modbus/TCP, MQTT, BacNet, and OPCUA protocols, a LoRaWAN® network server, to send collected data directly to cloud [13]. Fig. 3 illustrates the application of LoRa Sensor in in the Industrial Internet of Things.

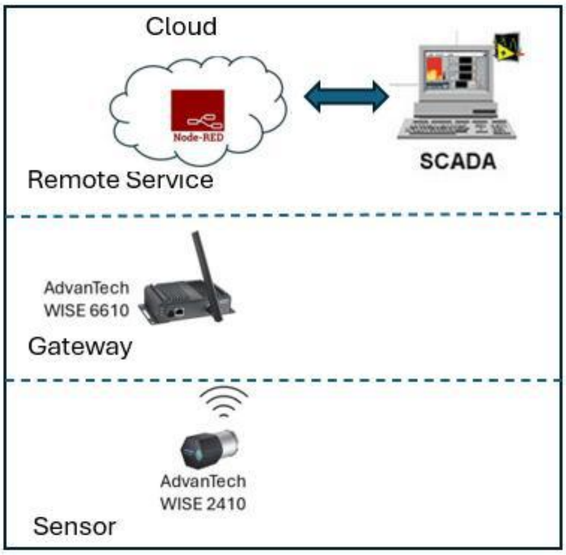

Fig. 3: Application of LoRa Sensor in in the Industrial Internet of Things.

V. METHODOLOGY

The proposed system architecture is based on Figure 4. IoT devices are the eyes and ears when one is not physically present and collect data, which is programmed for remote capture. This data can be received and analyzed to support and automate subsequent actions or decisions. The Advantech WISE-2410 smart vibration sensor and the Advantech WISE- 6610 LoRa WAN gateway were used as the key components for this project.

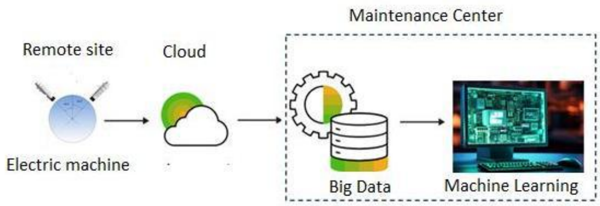

Fig. 4. Proposed system architecture.

The smart sensor, equipped with a magnetic base accessory, is attached to an electrical machine in remote site for data collection. The sensor captures vibration data from the machine and transmits it via LoRaWAN to the gateway. The gateway manages the data flow from the sensors. This gateway module establishes LoRaWAN networks applications. The gateway is equipped with various programs and protocols, such as Node-RED and MQTT (Message Queuing Telemetry Transport), facilitating data transmission and interpretation. By connecting the sensor to the gateway, the collected data is centralized, processed through the built-in translator, and transmitted to cloud.

Node-RED is a flow-based programming tool, facilitates the creation of data flow through a browser interface. The WISE-6610 comes with Node-RED pre-installed, enabling integration with the browser editor. The gateway includes all necessary packages software, so no additional installation is required. To enable data transfer to the cloud for advanced processing, the MQTT, also pre-installed on the gateway, connects with Node-RED.

Once the data is acquitted and routed to the cloud, a program is needed to collect and store it. Microsoft Excel is used for data storage and initial organization in maintenance center. It allows users to create charts, and various visualizations, as well as perform calculations with data inputs. For this project, Excel serves as a repository to track and manage all collected vibration data in a single file format before transferring it to other software.

The final software utilized in this project is LabVIEW [18]. LabVIEW is a computing environment that supports the development of algorithms for data manipulation and analysis. It also offers integration with other software, including Node-RED, Microsoft Excel, and Advantech systems, facilitating efficient data exchange and processing.

The block diagram of the algorithm of the personalized diagnosis method for the diagnosis of incipient failures in rotary electrical machines based in machine learning techniques is shown in Figure 5. The different stages of the proposed system are: (i) Feature extraction; (ii) Feature selection; (iii) Training set, and (iv) Test results.

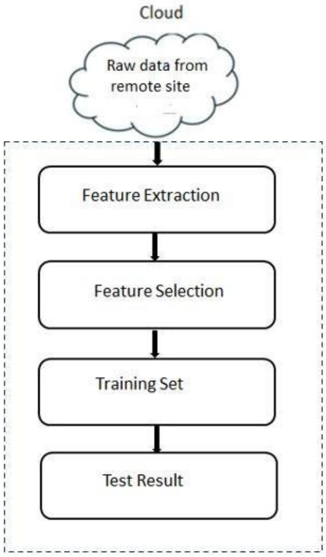

Fig. 5. Block diagram of algorithms implemented.

VI. CONCLUSION

In this paper, a methodology based in Internet of things (IoT), smart sensors, cloud computing and machine learning for assessing an electrical machine rotor's health condition under misalignment fault in remote site is presented. The methodology developed can diagnose several severity levels in an electrical machine by measuring the vibration signals with one vibration smart sensors. The feature selection allows obtaining the optimum set of features, first, by selecting the features that present the most relevant information related to the rotor performance and, after, by reducing the dimensional space. The project is very interesting and challenging at the same time. The LabVIEW programming was adequate for this project. In the next phase of the project, a new group will work on improving the performance of the system and employing new machine learning techniques. The results will be compared with the existing methods to be able to fine-tune the system.

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