A study into intelligent Neutral Section fault monitoring system on the Coal line using wireless sensor networks

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ABSTRACT: Machine learning a subdivision of artificial intelligence which is popular nowadays particularly where large amounts of data are to be evaluated unsupervised by applying algorithms thereby requiring less human effort to process the measurements. This paper presents an intelligent fault monitoring on the overhead wires using wireless sensor network (WSN). The current method used to monitor failures requires both foot patrols and vehicle measurements using cameras, however these methods are both labour and time intensive in preparing and analysing the data from the inspections. An intelligent method is proposed to reduce the amount of time spent on labour intensive inspections through data aggregation and machine learning. Machine learning offers additional flexibility for identifying the type of the faults, finding otherwise hidden patterns and grouping instances of events accordingly based on similarities. WSN will convey the measured data to the cloud via the router for computation thereby providing notifications in real-time and also the data can be viewed anywhere by the operator. K-means clustering algorithm will then be applied later using sensors data via Matlab/Simulink.

1 INTRODUCTION

Transnet has embarked on a fourth industrial revolution path (Transnet 4.0) were the infrastructure (bridges, rail tracks, tunnels and overhead wires) and machinery used for moving freight, jet fuel and port cranes will be embedded with sensors to detect failures and monitor the condition of the assets. These efforts are executed to improve operations, safety and also lowering the cost of maintenance thus enabling greater network availability for the coal corridor [7]. The relationship between freight and time (years) is vital were the amount of tonnages are expected to rise over time. The Coal corridor does not have available trains slots reserves and any failures have direct negative impact on the business as a whole resulting in dire annual performance. Due to increasing number of unreported incidents where arc runners are being damaged, balancing droppers and return/earth wire burnt-off, the number of Neutral Section incidents has exponential increased by 30% which prompted the need for an intelligent monitoring system that will detect failures. Continuous monitoring of infrastructure is vital because this will assist in detecting failures and the origin of failures by alerting the maintenance personnel to react proactively thus reducing the minute delays [8].

All these data needs to be processed and analysed before action may be taken, which leads to machine learning which is a subsequent of artificial intelligent. The core function of machine learning is to provide intelligent methods of interpretation and analysis of data to make sound decisions on addressing condition and fault detecting of infrastructure assets. The prompt increase on research and technological development, WSN are used on a specified area to simply gather and send information for processing and analysis. WSN has grown its reputation were the environment and infrastructure to mention the few is embedded with sensors to monitor the faults, temperature, health and natural disaster for safety by preventing loss of life or damages that may be catastrophic [2]. There are three most useful topologies (star, tree and mesh) utilised and these topologies are efficient and reliable for fault detection and condition monitoring processes due to that they can withstand severe environmental condition [10]. Star topology communication, each end nodes connects directly to the gate way were a single gateway may send and receive data. On this type of system the end nodes are not permitted to send messages to one another. Tree topology end node is connected to the router node were all the nodes are feeding into the gateway. The end node and router node always check for communication signal between the two before transmitting to the gateway. Lastly the mesh topology enables data to be sent from one node to the other that is within the range. This is one of the complex systems that enable vigorous communication and flexible network. These large amounts of data require flexible, efficient and cost effective tools for storage and analysis. The discovery of Wi-Fi IEEE802.11, ZigBee IEEE 802.15.4 and Bluetooth 802.15.2 yielded the foundation for machine to machine communication. The process allows machines to communicate, interpret and analyse the data autonomous without human intervention [11].

Machine learning particularly the unsupervised technique attempts to find the information from the input without the supervision of the person were there are no labelled or expected results from the input. There are three kinds of machine learning techniques which are supervised, unsupervised machine learning and reinforced learning. Unsupervised machine learning: In this kind of learning, the machine is provided with given sets of inputs and needs to classify the inputs autonomous according to the patterns without supervision. There are no expected results from this algorithm [1] & [12].

K-means clustering

The clustering algorithms are of many types and not all provide models for their clustering to be grouped based on the similarities, however k-means algorithm meets the criteria because it is quicker, easy to implement and able to handle enormous data. K-means clustering algorithm is a way of grouping data in the cluster based on their similarity [4]. The algorithm search for hidden patterns and classify the measured raw data from sensors objectively. There are no target variables from this algorithm, it usually learns by itself where there are no expected outputs or results.

K-means algorithm [9]

- **Starting point**
  – Put K randomly where the measured data to be clustered
  – Allocate each measured data to the group which has the closest centroid
- **Learning**
  Clustering algorithm
  – Calculate the distance to each cluster k centroid
  – Recalculate all the data points of the cluster
- **Application**
  – Repeat the process up until the data points do not converge anymore

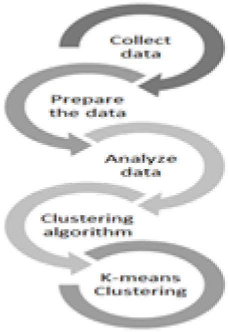

Figure 1. K-means clustering workflow

Euclidean distance is generally a method used to measure between two *x,y* points, Euclidean distance is the square root of the sum *x,y* squares of the difference between two data points as in equation 1. This method is greatly applied on determining the distance between two data *x,y* points mostly on clustering algorithm.

$$d(x_j,y_j) = [\sum_{j=1}^{n}(x_j - y_j)]^{1/2} \quad (1)$$

2 METHODOLOGY

Figure 2. Accelerometer installed on the Neutral Section

2.1 Data collection

Neutral Section (NS) is formally known as an arrangement of wires and insulation rod provided into the overhead track equipment to ensure that two phases from separate substation are kept apart while the electric locomotive pantographs traverse through the NS [5]. Electrical power is generated in three phase's and is displaced 120 degrees apart, the traction system utilizes the single phase supply where

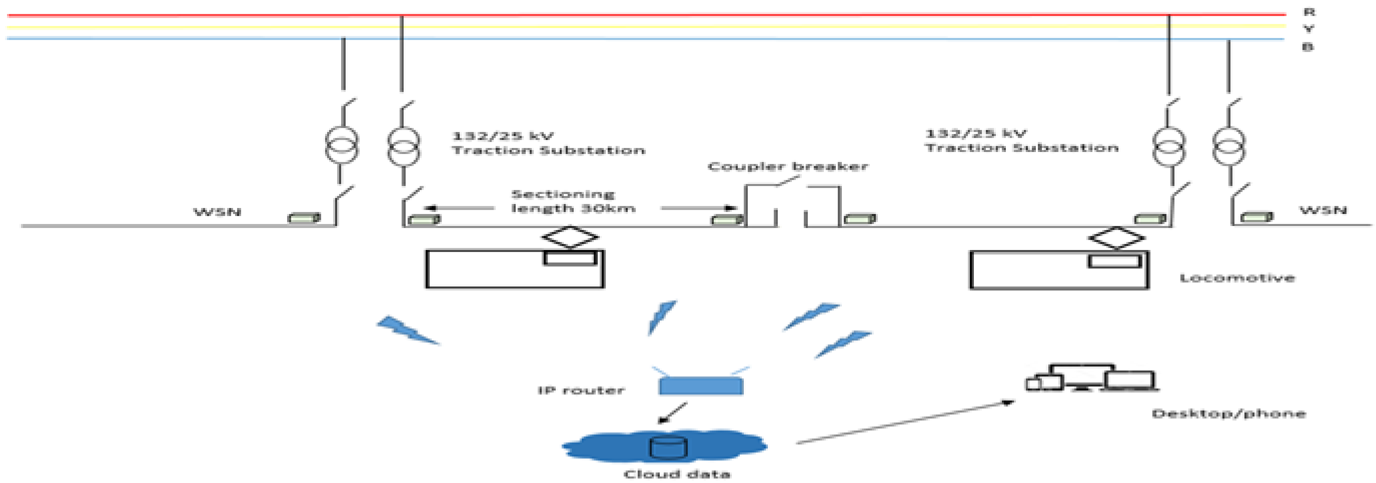

Figure 3. Proposed monitoring system on the Neutral Sections

two phases are used to feed the overhead wires. The loading of the phases should be balanced such that there is alternating of phases were the overhead wires are supplied and NS are provided on different sections. The NS if fitted with track magnets in between to de-energize the coil by switching the breaker and energizing the coil for switching on after traversing through the NS by restoring power back to the locomotive. This is complete to prevent the locomotive from drawing arc across the different phase supply. The NS is provided to prevent phase to phase contact while trains are not switching-off at the assembly. The NS has high mechanical strength and can withstand harsh environmental conditions. For a smooth interaction between Arthur Flur NS and locomotive pantograph, a stagger gauge or trolley vehicle fitted with pantograph is utilised to balance the NS with reference to the track. The stagger should be zero for all places were the NS is installed. An enclosure housing the sensors and power supply will be installed on top between arc runners and balancing droppers to measure vibrations and tilt angle on both side of the NS as shown on figure 2.

Data will be collected from sensors such as Non-contact Infra-Red (IR) temperature sensor MLX90614 and accelerometer ADXL345. The MLX90614 will measure the ambient temperature and object temperature from the return/earth wire conductor and lastly the ADXL345 will be mounted on the NS of the overhead wires to detect and measure the vibrations and tilt angle resulting from the damages caused by the trains not switching off. All the sensors are connected to the arduino uno board where the measured data is transmitted to the cloud (Thingspeak) via ESP8266 Wi-Fi module for private storage and analysis for simulation purposes. Two accelerometers will be installed and positioned as shown on figure 2 where the Arthur Flur NS fitted between the feeding arrangement.

2.2 Analysing data

The proposed system will monitor faults on the overhead wires using sensors were the data will be sent to cloud for online analysis and visualizations. Thingspeak allows measured data to be stored privately, carrying out online analysis for understanding relationships between different groups and scheduling computation to run on desired times [3]. The data will be stored online and it will be exported via a csv file to be further analysed depending on the user requirement.

2.3 Action

Data analytics can be executed online via Thingspeak or by exporting the csv file manually to execute the clustering algorithm via the Matlab. Also Thingspeak allows user to visualize, analyse and act on data online. Triggered events resulting from detected fault or were conditions are exceeded will be sent via twitter [6]. For the purpose of this paper, all the recorded data from sensors shall be exported to Matlab to perform the algorithm.

During the testing procedure two enclosures were installed on the NS to detect any failures. An overhead machine vehicle fitted with standard pantograph was used to detect any vibrations between pantograph and NS runners. The non-contact IR temperature sensor will distinguish between the object temperature against the ambient temperature. The interaction between other departments (Permanent way, Electrical, Signals, and Telecoms) is very crucial for the well function of the continuous monitoring.

First phase of the experiment: Install the device and let it run and measure without any external influence to see the behaviour of accelerometer readings (X, Y, Z) and temperature sensor.

Second phase of the experiment: Allow the overhead machine vehicle to run at different speeds 15km/h, 30km/h, 60km/h, 80km/h to check the behaviour pattern of the accelerometer (X, Y, Z). The behaviour of X, Y, Z changed and it can be observed that at high speed the vibrations are much greater than lower speeds.

2.4 Error analysis

Several experiments were executed to determine the behaviour pattern of vibrations and temperature variation from the overhead machine vehicle fitted with the standard pantograph. External influences such track cant, wind and rain; is evident as false alarms from generated data. It is seen that accelerometer behaviour is influenced by the following parameters;

- Overhead machine vehicle speed
- Contact wire height/ruling height
- Contact wire force
- Pantograph position
- Pantograph upliftment force
- Condition of track
- Wind speed

2.5 Improved method of measurement

Develop a mechanism to prepare and clean data particularly the data that is causing the outliers from the algorithm. Position the accelerometer correctly in reference to the spirit level so that the axes correlate. Lastly instead of measuring the temperature of return/wire will rather measure the 107/161mm² clamp were the wire is suspend, this reduces the distance in between and increases the sensitivity from the point of heat source. Develop an algorithm that will detect and remove outliers form the data since k-means is sensitive to outliers.

3 SIMULATION RESULTS AND ANALYSIS

Onsite simulations were performed at various speeds to determine the behaviour of X, Y, Z accelerations and angles resulting from the interaction between the pantograph and NS.

Thingspeak online analysis and visualisation

Figure 4. Ambient and Object Temperature

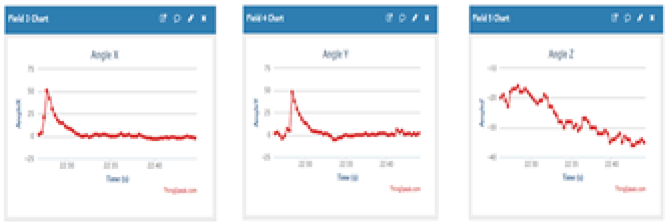

Figure 5. Vibration acceleration for X, Y, Z when the pantograph touches the NS

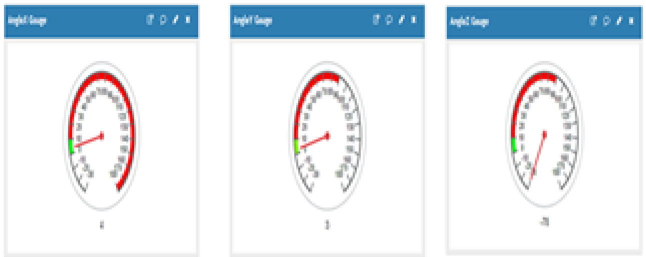

Figure 6. Vibration angle for X, Y, Z when the pantograph touches the NS

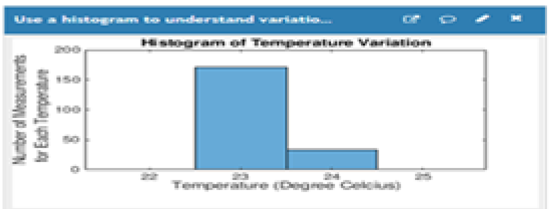

Figure 7. Online analysis for temperature variations

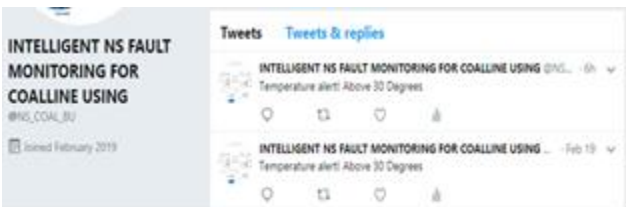

Figure 8. Real time alerts for detected failures via Twitter

Machine learning algorithm via Matlab

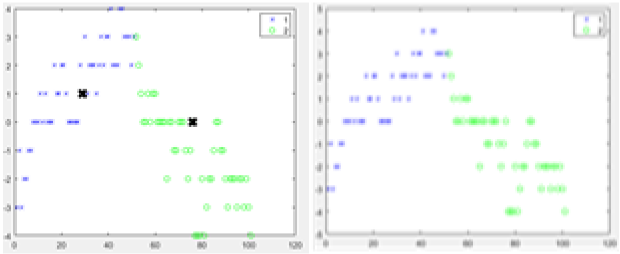

Figure 9. Clustered vibration acceleration

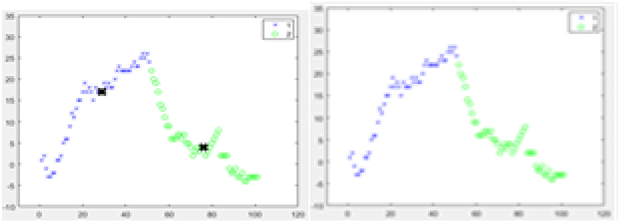

Figure 10. Clustered vibration angles

4 CONCLUSIONS

Intelligent fault monitoring system with good storage and processing tools will greatly benefit operation, safety and improve network availability that is efficient and reliable for the passage of trains. It can be observed that WSN has eliminated the need for wiring space and costs were the wireless sensors are able to collect and send large amount of data wirelessly to the cloud. The system was able to collect and send data to the cloud wirelessly, receiving triggered events in real time via twitter and execute k-means from the collected data from sensors, to be grouped based on their similarities. The intelligent fault monitoring makes it possible to determine the type of fault resulting from unbalanced or burnt-off droppers of NS. It is evident from the onsite simulations that the system is highly reliable and can continuously operate without interruption all day were it will assist with fault detection and diagnosis from the state of occurrence thus reducing the cost of monitoring.

5 ACKNOWLEDGMENTS

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6 FUTURE WORK

To detect the fault currents and overvoltage's caused by the locomotives from failing to switch-off at the NS. The intelligent fault monitoring system will provide accurate fault diagnosis on the type of the fault.

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