Development Of Iiot Based Condition Monitoring System For Rotating Machine Elements

Abhinav Gautam, Deepam Goyal, B.S. Pabla

Abstract: The condition monitoring and fault detection have gained popularity due to their potential benefits including improved productivity, durable costs, and increased system efficiency. In this paper, the application of the industrial internet of things (IIoT) based system has been discussed to diagnose the gear faults. The vibration and thermal signatures were acquired from the healthy and defective gears. The experimental set-up incorporates rack-pinion gears, one electric motor (for providing input torque), one vibration sensor, one temperature sensor and one mobile (as receiver for receiving the warning or precautionary maintenance schedule-based message). The acquired signals were then sent to thingspeak.com based IIoT system for online data monitoring and transmission. In the event of any vibration response going away from the permissible range, it is considered as a defect in the system. In such cases of possible failure, the system offers an early warning to the operator on their mobile device regarding high vibration levels. The outcomes reveal that the proposed methodology can help in avoiding undesired and unplanned system shutdowns due to gear failure.

Index Terms: Gears, vibration signatures, thermal signatures, industrial internet of things

1 INTRODUCTION

The gearbox is one of the most important transmission mechanisms in rotating machinery. Its health directly affects the normal operation of mechanical equipment. In the unrelenting working environment, the gearbox is prone to failure, and rotating machinery often does not stop to check at the initial stage of failure, so a single fault may induce other faults, resulting in complicated faults, serious economic losses, and casualties. The importance of real-time online monitoring is strengthening persistently as the industries try to enhance the machine availability and have a premature alarm of incipient breakdown. Due to recent advances in the enhancement of wireless network technology, the uses of internet-connected devices viz. smartphones and laptops have made the realization of a smart sensor in combination with signal processing circuitry a possibility. Therefore, it is required to implement the Internet of Things (IoT) which can recognize and deal with different types of failures within a machine for condition monitoring and aiding timely maintenance resolutions. Kannan et al. [3] designed a digital twin for grinding wheel as an information-sharing tool to connect, organize and collaborate with the production process to increase productivity and efficiency. The design includes product pre-knowledge component, Radio Frequency Identification (RFID) digital emulation and IoT powered wheel end-of-life prediction and service channel to be built and integrated. Theorin et al. [4] applied Line Information System Architecture (LISA) software used in the automotive industry, where processes are intermittent and the product flow is non-linear. LISA offers flexibility and scalability both for control of low-level applications and aggregation of higher-level information. In future LISA can be implemented to visualize decision support and integration of online optimization.

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Demetgul [5] demonstrated a fault diagnostic approach based on a multilayer artificial neural network to determine the worm gear condition. It was found that the proposed strategy can be used to predict the gearbox's oil level and speed as well as the heating patterns for all these operating conditions. Garcia-Ramirez et al. [6] suggested an approach based on thermographic image segmentation for fault diagnosis of the rotating machine. This approach can detect bearings faults, rotor broken bars, mechanical unbalance, misalignment, and also voltage destabilization in an induction motor's early stage of failure. Goyal et al. [7] built a low-cost non-contact vibration sensor for detecting the faults in bearings. The supervised method of learning, Support Vector Machine (SVM), was used as a tool to verify the sensor's effectiveness. To develop a framework for the diagnosis of faults for machine health monitoring, experimental vibration data collected for various bearing defects under different loading and running conditions were analyzed. Fault diagnosis has been accomplished using a discrete wavelet transform for denoising the signal. Mahalanobis distance parameters were used to choose the strongest characteristic of the related characteristics extracted. After that selected parameters have been passed to the SVM for the detection of various bearing defects. The results show that the vibration signatures acquired from the established non-contact sensor correlate well with the data obtained under the same conditions from the accelerometer. Saez et al. [8] developed a framework for assessing the performance of real-time hybrid simulation manufacturing networks. Continuous and discrete variables of different machines are tracked for performance analysis using a virtual environment that works synchronously with plant floor equipment as a guide. Data are collected from machines using IoT solutions. Leitao et al. [9] introduced a service-oriented architecture model and integrated different types of digital software tools to construct an engineering framework for manufacturing system acceptance, setup, simulation, a basic outline, control, and monitoring. Xiaoli et al. [10] developed an intelligent web-based fault prediction framework. The program aims to improve the quality of work and the smart level of detection of faults. First, the system's characteristics are examined, and then the system's functional architecture is configured to perform detailed condition monitoring, reliable information transmission, and computer-intelligent fault prediction information processing. Civerchia et al. [11] designed the

NGS-PlantOne solution to allow widespread condition monitoring of industrial equipment via battery-powered IoT sensing devices, enabling predictive maintenance applications to be built in the scenario considered.

2 EXPERIMENTAL SET-UP

An experimental setup, Gearbox Diagnostics Simulator (GDS), has been used to test revolving machine defects. The experimental device had the function of replicating industrial drive trains, particularly as an academic study tool. Fig. 1 shows the experimental setup used to detect the defects and faults of the rotating parts of the machine. The test rig consists of a single shaft gearbox with bearings and a mechanical brake operated by a PC. The machine parts were installed in such a way as to achieve and use a wide range of drive train configurations for testing. It was designed to handle large loads. It also has a fluctuating frequency drive which governs the frequency of the input shaft. The test rig specifications are given in Table 1.

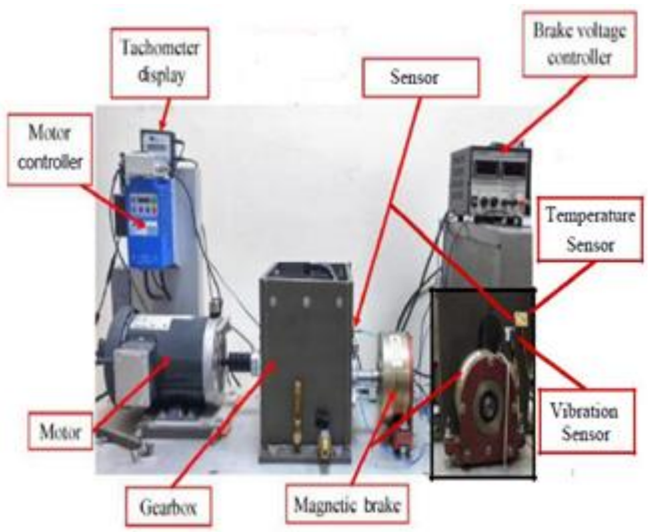


Fig. 1*. Test rig used for experimental measurement*

The gearbox, comprising input and output shafts, is an important part of the rig and opens a wide scope for different types of research work. The specifications of the gearbox are listed in Table 2.

Table 1

GEARBOX DIAGNOSTIC SIMULATOR SPECIFICATIONS

PARAMETERS	*DESCRIPTION*
Fabricator	*Spectra Quest*
Electric Motor	*3 HP, 3-φ*
External loading	*Magnetic loading*
Rotational speed	*0 – 3000 rpm*
VFD	*Lenze*
Measurements	*L x B x H = 100cm × 50 cm × 60 cm*
Weight (approx.)	*90.7 kg*
Foundation	*Aluminum cast base with 8 rubber I insulators die 2.7 mm*
Bearing	*Deep groove ball bearing*
Gear box speed reduction	*Single-stage track gear Reduction*
Load potential	*0.125 N-m to 24.75 N-m*

Table 2

SPECIFICATIONS OF GEARBOX

SPECIFICATIONS	*VALUES*
Length	*27.5cm*
Height	*26.5cm*
Width	*19cm*
Number of pinion teeth	*29*
Number of gear teeth	*100*
Dimensions	*L x B x H = 29.5cmx19cmx26.5cm*
Central distance of gears	*9.656±0.1cm*
Shaft radius	*1.23cm*
Reduction ratio	*3.45 :1*
Pressure angle	*20o*

Fig. 2 illustrates the state of the gear with specific fault frequency. At various loads (no-load (0), half load (5.25 N-m) and full load (10.5 N-m) and running (900, 1200 and 1500 rpm), tests were performed on the GDS system using two gear samples i.e. healthy gear (H) and 50% chipped faulty gear (CTL50). Vibration sensor ADXL335 and temperature sensor LM35 fixed to the gearbox to acquire vibration and thermal signature.

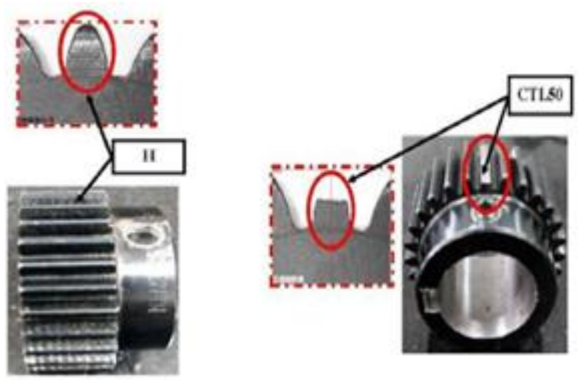


Fig. 2. *Spur gear with different severity of faults*

4 DATA ACQUISITION SYSTEM

A data acquisition device for the microcontroller (Arduino UNO) was taken as a central signal processing hub. This device uses LabVIEW software installed on a PC via a USB port to connect vibration and thermal signals with the Arduino board. Fig. 3 shows the schematic diagram of the data acquisition system used.

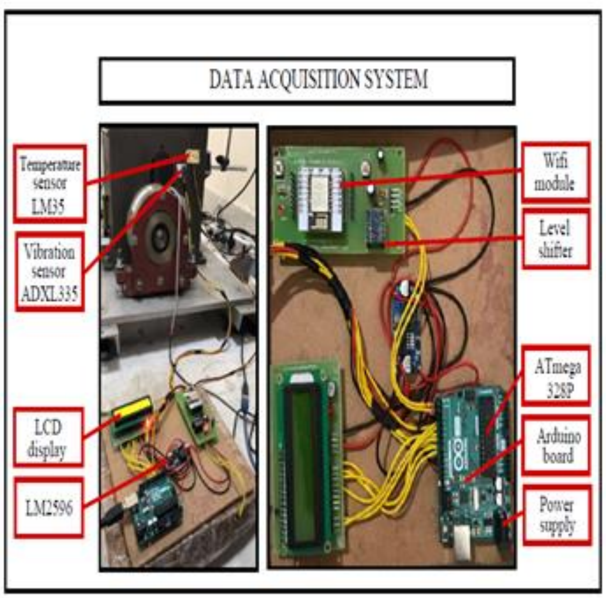


Fig.3. *Data Acquisition System*

4.1 Description of the Smart Sensing Unit

The smart sensor unit designed is a monitoring device based on a microprocessor that can capture 3-D vibrations and temperature profiles. As shown in Figure 2 system components were illustrated; here, vibration sensor ADXL335 and temperature sensor LM35 collect the data of healthy and defected gear CTL50 under different loading conditions.

4.1.1 Vibration sensing by ADXL335

The ADXL335 is a 3-axis vibration sensor with a signal-controlled voltage output, which is compact, thin, low power. It measures acceleration with a wide range of ±3g.

4.1.2 Temperature sensor

LM35 is an effective IC temperature sensor with a temperature-related performance (in degree Celsius). The operating temperature range varies from -55 ° C to 150 ° C. In response to each ° C rise/fall in temperature, the output voltage varies by 10mV, i.e. the level factor is 0.01V / deg C.

4.1.3 WI-FI module ESP8266

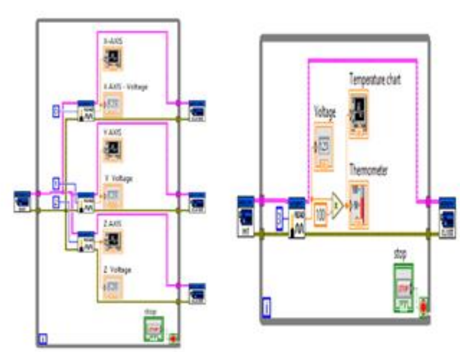
The ESP8266 is an inexpensive Wi-Fi microchip with microcontroller usability. This compact module enables microcontrollers to attach and make effective connections to a Wi-Fi network. It is often used to create embedded applications for cloud computing. The microcontroller employs UART with a defined Baud rate to interface with the ESP8266-01 module.

4.1.4 Microcontroller

The Arduino comes in a variety of different types, such as Arduino Uno, Arduino Mega, Arduino Nano, Arduino Netduino, Arduino Lilypad, which makes it difficult to choose the correct one, but variety also enables versatility in selecting the ideal solution. Arduino Uno is an ATmega328-based microcontroller board. It has 14 digital input/output connectors (which include 6 as PWM endpoints), 6 analog inputs, 16 MHz ceramic resonators, USB interface, a power jack, and a reset button.

5 RESULTS & DISCUSSIONS

Vibration and thermal signatures under experimental conditions are calculated in the proposed study. The ADXL335 and LM35 sensors were used to gain vibration and thermal signature from the test rig under different loading and running conditions. Two separate programs made for the collection of temperature and vibration data of healthy and faulty gear and signal analysis is done using LabVIEW software as shown in Fig. 4. For interface LabVIEW software with Arduino, the LIFA_base program is used which is uploaded in microcontroller ATMEGA3688 of Arduino. Using LabVIEW, 1500 data sample for both vibration and temperature is collected in 15 sec for different operating conditions and this process is repeated for five times and mean value of temperature and vibration amplitude is taken for x, y and z-direction for each second of all loading conditions to achieve better accuracy in results. After having the highest values of vibration amplitude for each second, the graph is plotted for temperature and vibration amplitude in volts against time for each x, y and z-direction for healthy and faulty gear at different operating conditions.



(a) (b)

Fig. 4. *LabVIEW Programs (a) Vibration (b)*

Temperature

Table 3 shows the maximum values of vibrations at full load and different running conditions in x, y and z directions for healthy and faulty gear CTL50.

TABLE 3

Maximum vibration values in volts at full load

RPM	Gear Condition	Vibration Amplitude (V)		
		X axis	Y axis	Z axis
900 rpm	Healthy	1.946	1.578	1.89
	CTL50	2.17	1.598	1.989
1200 rpm	Healthy	1.976	1.61	1.896
	CTL50	2.169	1.598	2.056
1500rpm	Healthy	2.016	1.627	1.963
	CTL50	2.235	1.599	1.996

After conducting experiments for healthy and faulty gear at different loading and running conditions, it was found that temperature and vibration amplitude is higher for faulty gear than healthy gear at full load and 1500 rpm. From Fig. 5, it is found that the highest value of the x-axis vibration amplitude is 2.235 volt for faulty gear CTL50 and for healthy gear it is 2.016 volt at full load and 1500rpm.

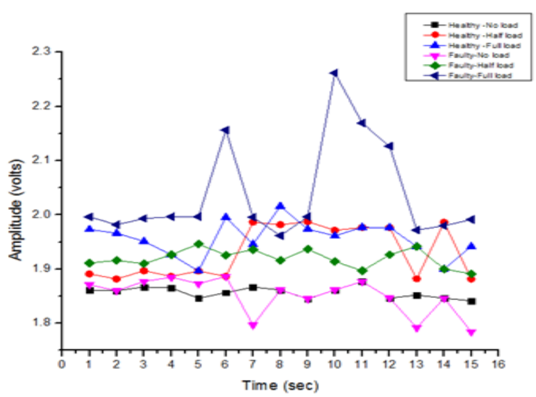


Fig. 5. *X axis vibration for healthy and faulty gear*

Table 4 shows the maximum values of temperatures at full load and different running conditions for healthy and faulty gear CTL50.

TABLE 4

Maximum temperatures values in Celsius at full load

RPM	Gear condition	Temperature (Celsius)
900 RPM	Healthy	31.87
	CTL50	52.43
1200 RPM	Healthy	46.57
	CTL50	48.04
1500 RPM	Healthy	54.98
	CTL50	62.01

From Fig. 6, it is found that maximum temperature value for faulty CTL50 gear is 62°C and for healthy gear, it comes 55 °C at full load and 1500 rpm. Real-time analysis is done using the IIoT platform for which maximum temperature and vibration amplitude is converted into ADC value, as CTL 50 faulty gear is considered for doing a comparison with healthy gear and maximum value of vibration amplitude for faulty gear is 2.235 volt.

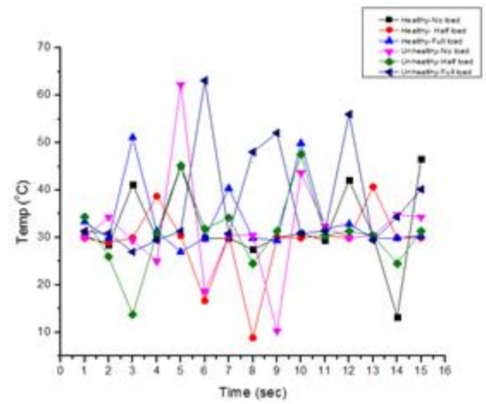


Fig.6 *Temperature values for healthy and faulty gear*

This maximum value of vibration amplitude is converted into ADC (analog to digital) value of Arduino which is calculated as below:

5 Volt = 1023 ADC value
1 Volt = 1023 / 5 ADC value
2.235 Volt = 1023/ 5 * 2.235
2.235 Volt = 457 ADC value

The IIoT system rechecks the signal after a specified time interval and again finds the average, compares against the preset threshold limit and sends a warning message to the end-user if required. The above-calculated value of 457ADC(analog to digital converter) for vibration and 61oC for temperature is set as the threshold value of vibration amplitude and temperature for message alert if vibration amplitude and temperature value exceeded the threshold value, then Wi-Fi module will send an alert for vibration on mobile. Fig. 7 shows the message alert on the mobile phone.

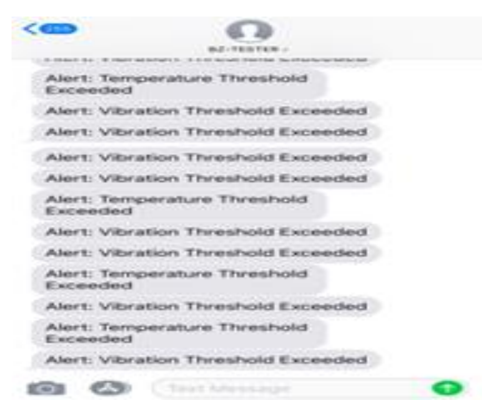


Fig.7 *Message alert for Vibration and Temperature*

6 CONCLUSIONS

With the signs of progress in sensor hardware technology and cost-effective materials, sensors are expected to be attached to all the items around us, so that these can interact with each other with minimal human mediation. This paper presents an IIoT based real-time condition monitoring system for detecting the defects in gears. The proposed system mainly performs three functions viz. measuring the vibration and thermal responses, comparing it with a reference signal and sending an alert message to the mobile of end-user. An alert message will be sent only if the mean vibration response exceeds a predefined threshold limit. Such high vibration and thermal responses may be caused due to any defects in the gearbox. The developed system performed successfully when tested in laboratory operating conditions. Such a minimal-cost IIoT-based condition monitoring system has huge potential for the optimal use of IoT-based condition monitoring to assess the machine's failure and monitoring aspects.

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