Real Time Condition Monitoring System for Industrial Motors

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Abstract— **In generally, predictive maintenance of induction motors is well suited for small to larger scale industries in order to reduce downtime, increase efficiency and reliability. In this paper, the vibration and temperature of the induction motor is analyzed in order to gather specific information that can predict motor's bearing failure. Well analyzed vibration signal easily shows the difference between the running operation of the healthy and faulty motor. Using IoT, this paper shows Real Time Condition Monitoring System for Industrial Motors.**

Keywords— Internet of Things, Induction Motor, Vibration Analysis

I. Introduction

Industries of this modern era are mainly concerned with quality and quantity of production over a period of time. Together with production requirements, an industry works to achieve its long and short term goals which determine the success or failures of that particular year. Almost every industry has incorporated the use of motor to accomplish its operational requirements.

Induction motors are the most common among AC motors used in industries today. There are in fact many types of induction motor available that are categorized under single phase and three phase motors. AC motors are chosen prior to DC motors as it requires a single power source whereas DC machines require separate power sources to the rotor and stator of the motor. Apart from this, there are other factors which make induction motors well suited to industrial usage [1].

Furthermore, motors are an essential machine and it also has a tendency to fail at some point in time. Taking industrial motors as an example, factors such as amount of lubrication, electrical considerations, motor ventilation, alignments and motor load are some possibilities that can be reason for motor failure. These factors result into motor vibrations or rise in motor temperature to critical levels [5].

The main aim of this research is to develop a real time monitoring system to monitor the vibration and temperature of industrial motors. From the literature review it is known that motor failure can be detected through measuring temperature and vibration levels [3][5]. This is accomplished through the use of sensors that take vibration and temperature data and interface this with the appropriate software. Upon which, the software displays sensor data for a span of time while also storing this data in a local database or to cloud. Also, an important aspect of this paper is to monitor system data for undesired conditions that may occur and alert these to maintenance team at work place [1].

Finally, this paper presents various experimental data analysis. Data from the sensors is analyzed and transformed into an appropriate form (Acceleration vs Frequency) to monitor vibration peaks. At the same time temperature data is also recorded which helps to make a reliable decision

II. Hardware And Software Configuration

A. Hardware Components

For vibration measurement, piezoelectric sensor (accelerometer) suited due to its light weight, easy placement and easy configuration. Microcontroller usage is best for acquiring data. Waspmote IDE pro v1.2 board have been used for this research which has the ability to acquire sensor data, communicate with other devices, store information in local, cloud server and alert the user when fault is detected. Fig. 1 shows block diagram of the hardware connections.

B. Cloud Storage

Data that is obtained from the sensors are transferred wirelessly to the local and cloud server for analysis. Once the data is received, a system has been devised that analyzes the raw data. On the other hand it will also save the raw data to the SD memory. The program has been set to process real-time data and store it to the cloud with Esri cloud computing platform. This saved data is accessible from anywhere via internet.

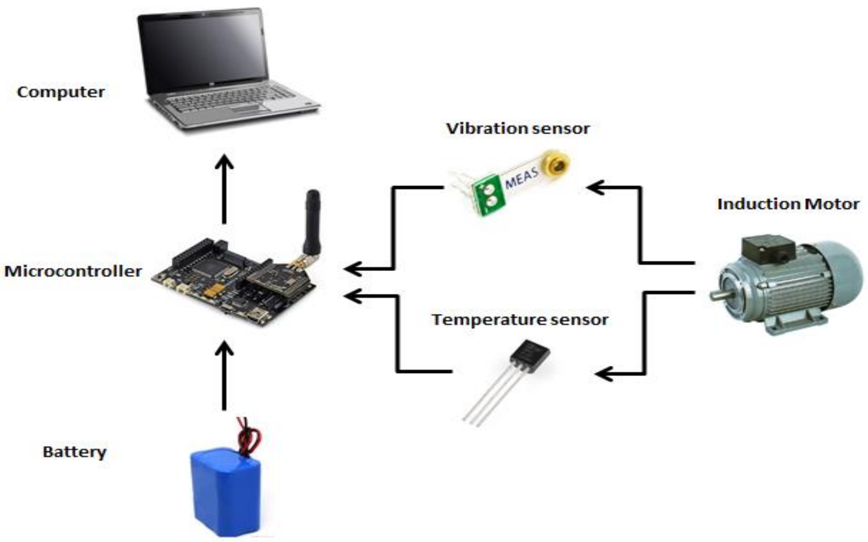


Fig. 1. Hardware connection of the setup.

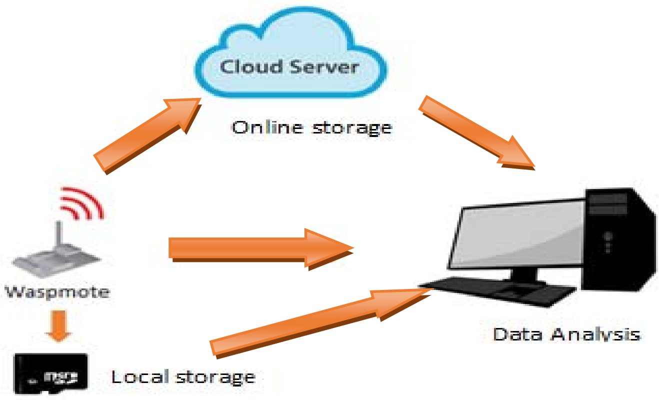


Fig. 2. Data storage and analysis technique.

Fig. 2 shows the data storage and analysis technique that has obtained from the microcontroller. Instead of logging single point data, queues are collected from the Waspmote Pro, and packets of data is pushed to the cloud together. This system is effective as it saves bandwidth while saving memory space for computer to push every data to the cloud making HTTP Client connection [4]. IoT has improved data aggregation, data access and offloading. These data is stored at a global location making it easy for accessibility and analysis.

C. Sensor Placement

The two basic sensors incorporated in this project are thermistor (Temperature measurement) and accelerometer (Vibration measurement). Most important aspect is to determine an effective sensor placement technique [3]. Improper sensor attachment would result in giving incorrect vibration data which is not suitable for motor failure detection.

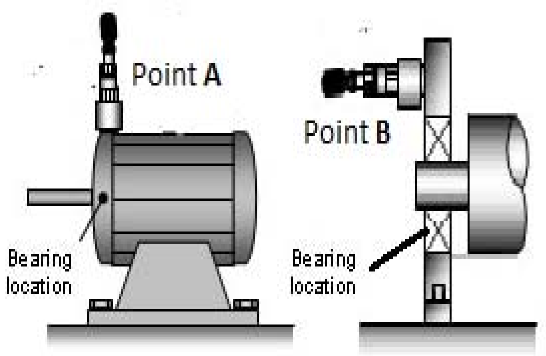


Fig. 3. Two possible position for sensor placement [3].

Bearing failure is the most common issue for motor failure [3]. The two points, Fig. 3 close to bearing location for vibration measurement and Fig. 4 for temperature measurement, are possible attachment areas that would provide appropriate reading data.

The sensor data gathered from point A was pulsating peaks that are around a common region (group of points). On the other hand, the sensor data obtained from point B displayed a lot of distortions as the accelerometer does not seem to be stable around common region. More importantly, the data set at point B seems to be incorrect when compared with the data set from A. Therefore, point A is selected for this Research which would be a more effective point for vibration sensor placement.

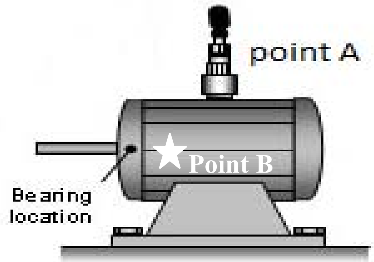


Fig. 4. Temperature sensor placement [3].

The temperature sensor placement in Fig. 4 encountered similar scenario as the vibration sensor. The placement at point A showed great distortions in reading whereas point B temperature readings were more stable and this point was selected for this research.

D. System Design

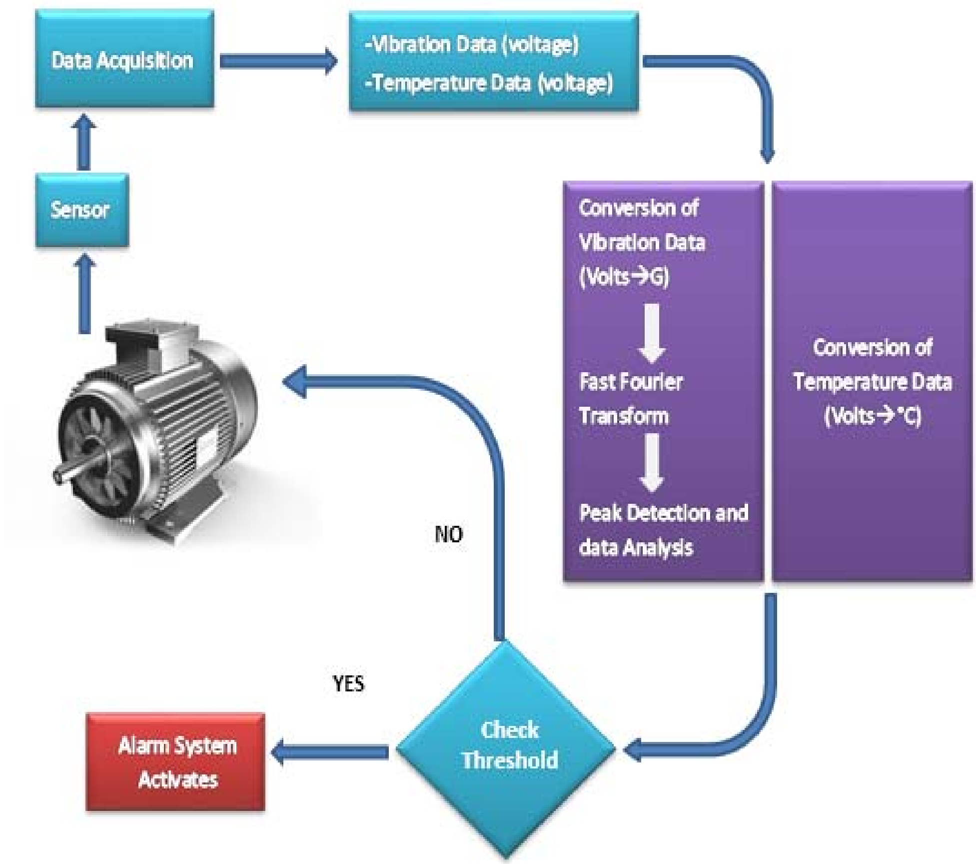


Fig. 5. Flowchart of the overall vibration monitoring system.

In this Research a three phase industrial AC motor was used for experimental purpose. The motor rating is shown in Table 1 (Class A). Sensors (accelerometer and thermistor) are attached to the motor according to the description given in the previous section. Sensor data was collected and processed using Waspmote and compared with the threshold value to trigger alarm if three is a prediction of failure. Fig. 5 shows the overall system flow diagram.

Three phase industrial asynchronous induction motor ratings are shown in Table I.

TABLE I. INDUCTION MOTOR RATING.

Parameters	Unit	Value
Voltage	V	380-415
Frequency	Hz	50
Power	kW	0.55
Speed	RPM	1390
Current	Amps	1.42
Power factor	-	0.751
Efficiency	η	72.1

III. METHODOLOGY

A. *Temperature Diagnostics*

Temperature is a significant factor in determination of motor condition. Along with vibration and noise, motor temperature also increases as the motor condition gets worse.

TABLE II. MAX. ALLOWABLE TEMPERATURE VALUES FOR DIFFERENT MOTORS [5].

Insulation Hot Spot		Typical Surface
Class	Temp (°C)	Max Temp (°C)
A	105	80
B	130	105
F	155	130
H	180	155

Table II shows temperature data for different motor insulation classes. Typically there are four different insulation classes. Each of the four insulation classes must be able to withstand max temperature while also cater for any extra rise in temperature from normal operating conditions at full load [5]. Also, the letters for each classes of insulation holds its own importance as it relates to the type of working operation a motor is designed for. Table 2 relates to the maximum temperature that one might expect at the core of the stator that is also known as the Insulation Hot Spot and also contains the maximum temperature the surface of the motor would reach. These data will be used to determine the threshold value for motor failure.

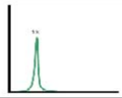
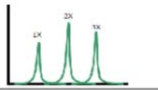
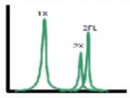
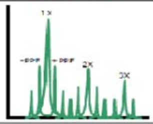
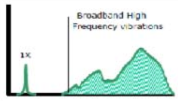
B. *Vibration Diagnostics*

Loose components, motor imbalance, resonance or the bearing failure are very common reasons for motor vibration, which in turn result the failure. The basic vibration measurements are usually done using an accelerator that works on the piezoelectric principle [6].

These acquired signals consist can further be analyzed using Cepstrum/Quefrency analysis, Short Time Fast Fourier analysis (STFF) and Power Density Spectrum analysis (PDS) [8][9]

Table III shows the important aspects of Vibration Analysis Technique associated with the Electrical Signatures Analysis Technique. Different mechanical faults with their spectrum and vibration pattern are shown.

TABLE III. VIBRATION DIAGNOSTIC TABLE FOR INDUCTION MOTOR FAULTS [7].

Mechanical faults	**Typical vibration pattern**	**Typical Spectrum**
Mass unbalance	1X	
Misalignment	2X, 3X	
Stator eccentricity	2XFL* *FL = Freq. line, e.g. 50/60 Hz	
Rotor eccentricity	PPF** sidebands around 1X, 2X, .. **PPF = Pole Pass Frequency	
Bearings wear	High freq. broadband vibrations	

C. *Bearings Fault Monitoring*

Bearing are the rolling element in the electrical machines that can give the high frequency components of vibration. Piezoelectric sensors (accelerometer) can easily be placed near the bearing in three different directions which are known as axial and radial direction where radial direction consist of horizontal and vertical direction. Since this paper is mainly focusing on the bearing fault therefore axial direction is being ignored and sensor has been attached to the x and y direction of the bearing. The closer the sensor to the bearing, the more accurate measurement is obtained [3].

IV. TEMPERATURE ANALYSIS

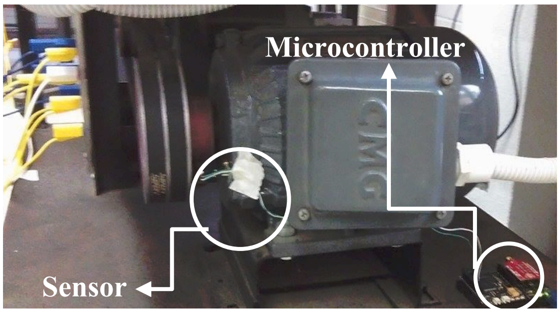


Fig. 6. Temperature Sensor in test bed.

The temperature data from point A (Fig. 3) is been altered by motor fan. Hence, temperature sensor is placed close to the stator frame as shown in Fig. 6.

For this research, a new motor is being used and observed that the temperature is within the range over a period of time shown in Fig. 7.

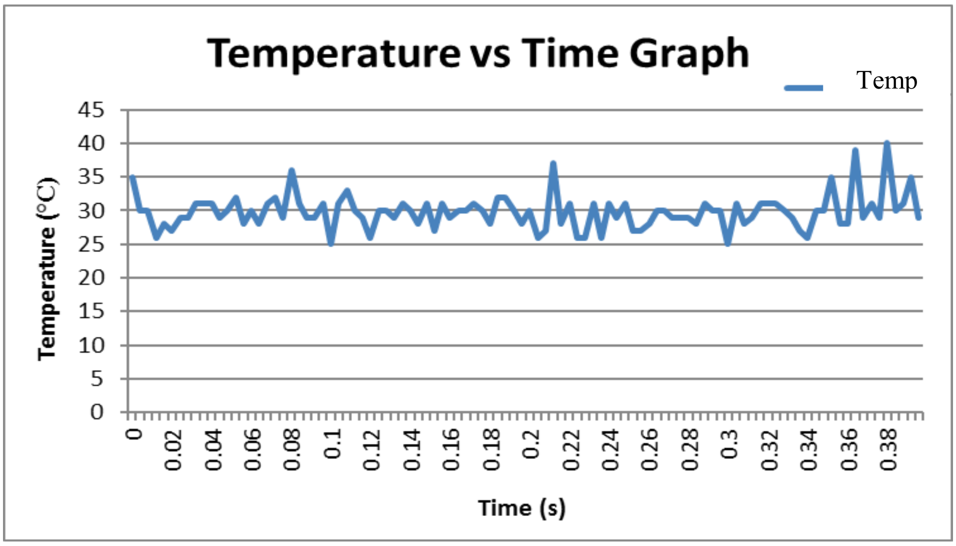


Fig. 7. Temperature sensor data over a period of time.

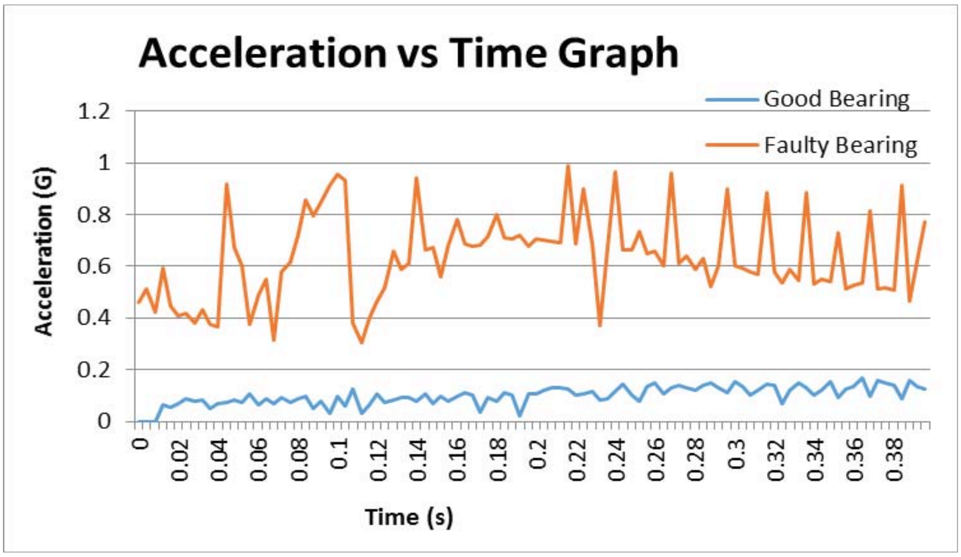


Fig. 8. Good and bad motor vibration plot in time domain.

V. Vibration Analysis

For bearing failure, acceleration data is very important for detection of the faults. This paper further shows different acceleration level recorded for different motor condition.

Fig. 8 shows the time domain signal of new and faulty bearings running under no load condition. It also explains the comparison made between the good and bad motor with respect to their acceleration amplitudes. Both motor is running at the maximum frequency of 50Hz. From the graphical representation (Fig. 8), it clearly indicates that max acceleration of a new bearing reaches around 0.09 whereas motor with faulty bearing accelerates to the average value of around 0.7 which yields a lot of difference.

VI. Fast fourier Transform

This research requires analysis of data into different forms of frequency to determine bearing issue. The acquired vibration signal is transferred from time domain to frequency domain. This fundamental step obtains the frequency plots which can further be used to compare frequency spectrum from a new to faulty bearing of the induction motor. Equation 1 shows acceleration waveform formula.

$$a(t) = a_0 + a_1 \sin \omega_1 t + a_2 \sin \omega_2 t + \ldots \qquad (1)$$

Fast Fourier Transform (FFT) equation is applied to the raw data for analysis in frequency domain is given in equation 2:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{j\omega t} dt \qquad (2)$$

Where $\omega = 2\pi f$ and f = frequency of signal.

The FFT new and faulty bearing conditions are shown in Fig. 9 and 10. The Fast Fourier Transform analyzed the raw data so that important signals can be identified to come up with accurate conclusion. Comparing the FFT graphs of good and bad motor, the good motor's average peak rises to up to 0.8 (Fig. 9) whereas bad motor's value rises to up to 3 (Fig. 10). Lab-view software is used for FFT analysis for the research.

VII. Vibration Monitoring System

Using vibration analysis techniques, motor faults can be detected early enough to allow maintenance team to take action. Equation 3 shows vibration velocity that is used in case of harmonic vibrations.

$$v_i = \hat{v} * \cos \omega_1 t \qquad (3)$$

Acceleration, speed and displacement amplitudes are derived as function of rotating speed. The RMS value is calculated using the formula given in equation 4.

$$v_{eff} = \sqrt{\frac{1}{2}\left[\left(\frac{\hat{a}_1}{\omega_1}\right)^2 + \left(\frac{\hat{a}_2}{\omega_2}\right)^2 + \ldots + \left(\frac{\hat{a}_n}{\omega_n}\right)^2\right]}$$

$$= \sqrt{\frac{1}{2}(\hat{s}_1^2 \omega_1^2 + \hat{s}_2^2 \omega_2^2 + \ldots + (\hat{s}_n^2 \omega_n^2))} \qquad (4)$$

$$= \sqrt{\frac{1}{2}(\hat{v}_1^2 + \hat{v}_2^2 + \ldots + \hat{v}_n^2)}$$

The above analysis sets vibration velocity to its standard limit, if the limits are exceeded, faults are identified on the electrical machine.

VIII. Alert System

The monitoring system has been designed to monitor vibration and temperature data. To detect excess vibration or temperature readings on a particular motor, the system has been set to a threshold value close to 0.9 (acceleration value) and 70 degrees for temperature. Taking the failure mark as a threshold value would indeed lead to motor failure before maintenance work may begin. Therefore, after analysis the threshold value has been set to a point before motor failure phase and up till the extreme vibration level a motor is designed to endure.

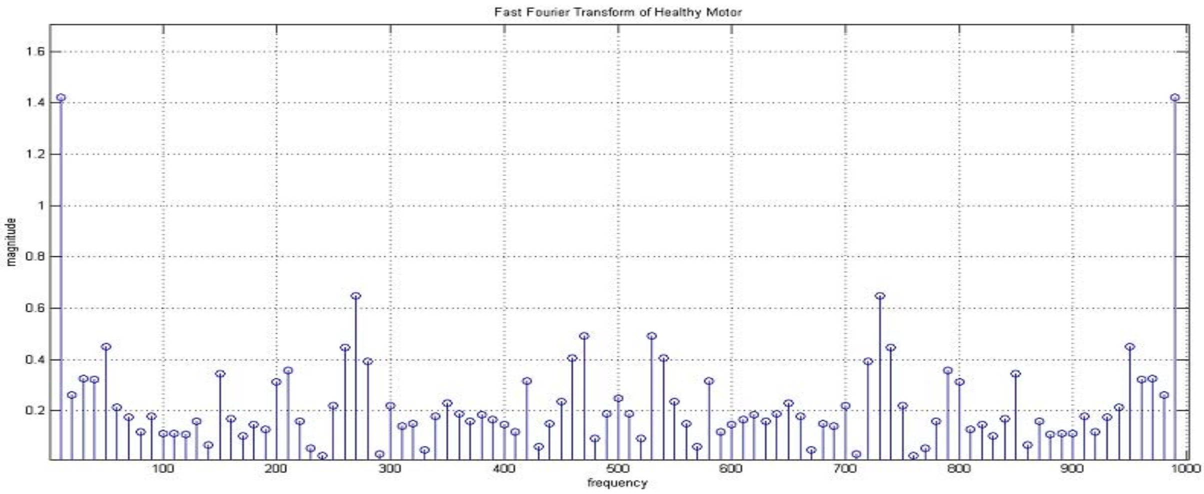


Fig. 9. FFT of a healthy motor with new bearing.

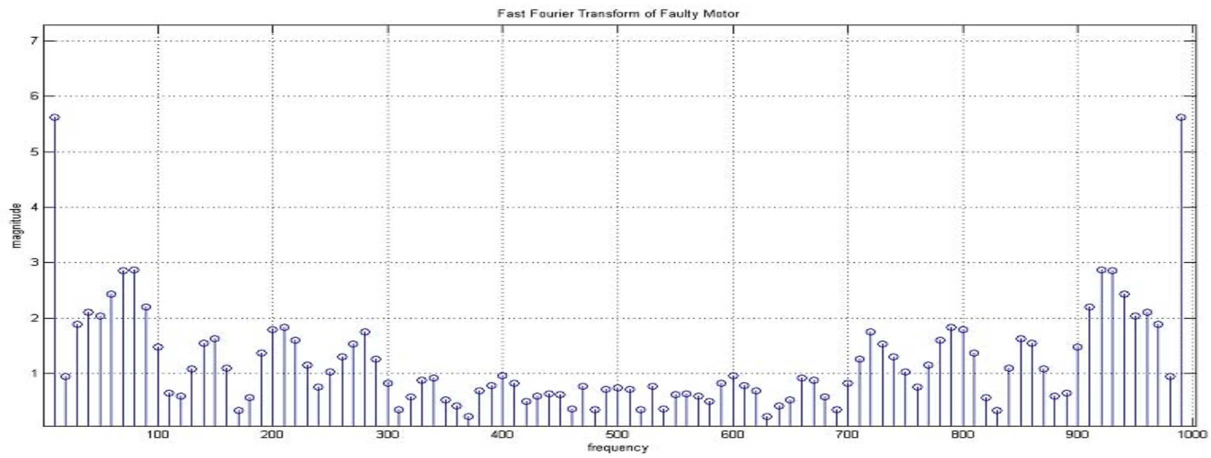


Fig. 10. FFT of a faulty motor with worn bearing.

Vibration on a new motor may increase up till 0.1443 to 0.2237 G [2]. This level is permissible for a medium sized motor. If it exceeds this limit, the alarming system will alert the maintenance team. Fig. 11 shows the schematic diagram of how the alert system operates. Alarming technique works using the GPRS system (local network) interfaced to the microcontroller. The GPRS shield is a wireless interface for the microcontroller (Waspmote PRO). The microcontroller has been coded to send out alert messages/calls to the maintenance personal at remote location. This system immediately activates if set threshold value is triggered 5 times at a set interval of 15 minutes interval from the point of first trigger to avoid any false alarm.

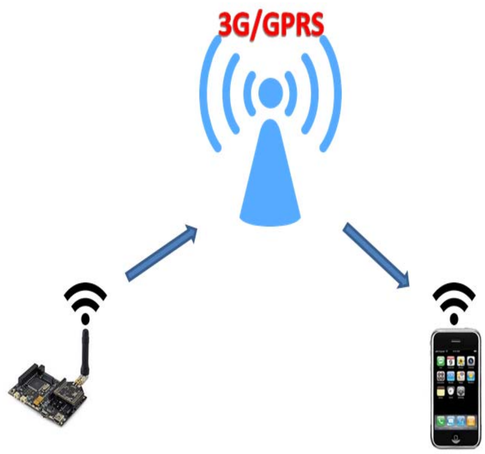


Fig. 11. Alarming system overview.

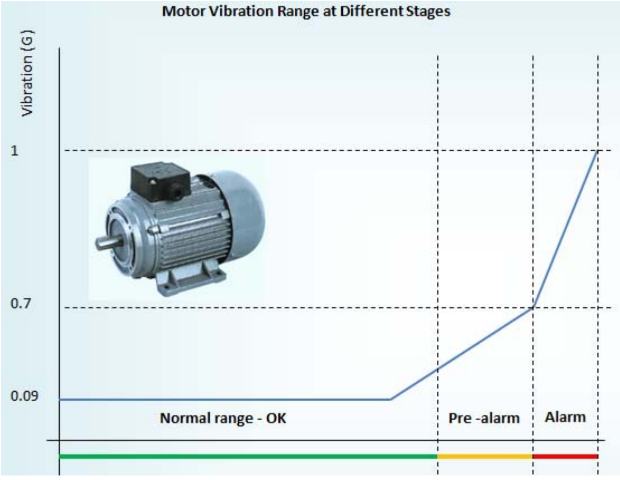


Fig. 12. Alarming stages.

Fig. 12 displays alarming stages at different vibration level. The green line indicates that the motor is running normal without any problem, orange line indicates that the motor needs to be checked and red line shows that some action needs to be taken for motor maintenance or motor replacement.

Fig. 13 is the overview of the system design hierarchy which shows the three important levels of this research on motor condition monitoring. Finally a proposed design is provided in Fig. 14 which is an overall idea of how this system can be implemented in industries.

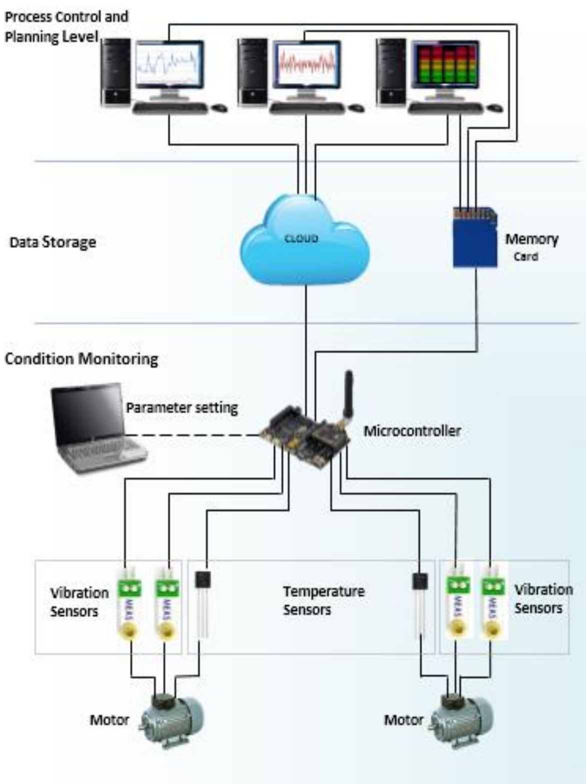


Fig. 13. Overall design.

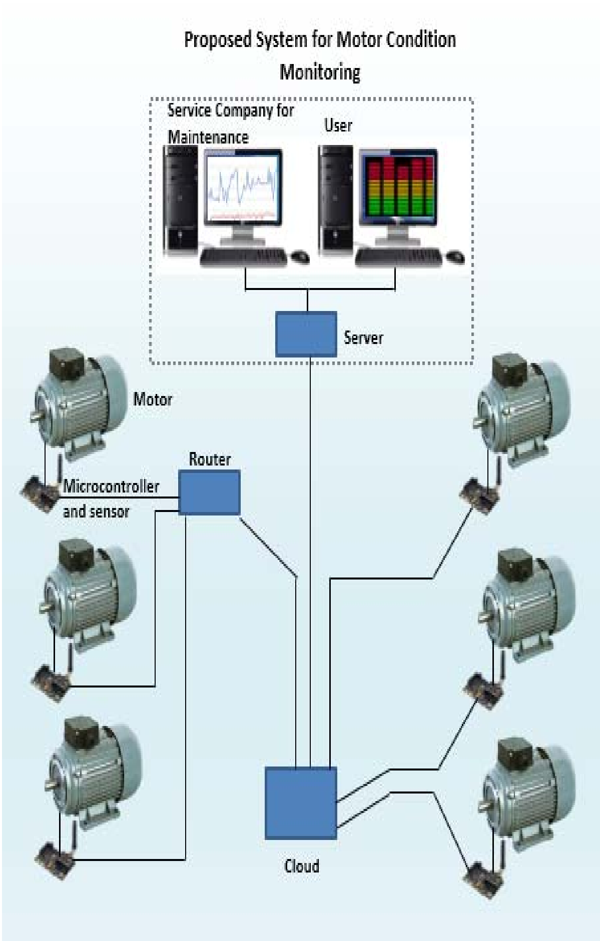


Fig. 14. Proposed Design.

IX. CONCLUSION

The advancement of this research is the improvement of monitoring system for motor's real time condition. With the help of IoT, data storage, retrieval and access has been made user friendly. Any issue with motor failure due vibration can easily be informed to the ultimate user through IoT. This research successfully designed and implemented a versatile motor condition monitoring system using the remote sensing (RS) and IoT technology which could reduce downtime for many industries and manufacturing companies.

The detection accuracy can be improved using other intelligent methods, such as Short Time Fast Fourier Transform (STFT) or even Cepstrum analysis and Power Spectrum Density (PSD) which currently under investigation of this research project.

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