IEEE PEDS 2017, Honolulu, USA
12 – 15 December 2017

IoT-Based Traction Motor Drive Condition Monitoring in Electric Vehicles: Part 1

Jakkrit Kunthong[1], Tirasak Sapaklom[1], Mongkol Konghirun[1], Cherdchai Prapanavarat[1], Piyasawat Navaratana Na Ayudhya[1], Ekkachai Mujjalinvimut[1], and Sampast Boonjeed[2]
[1]Department of Electrical Engineering, King Mongkut's University of Technology Thonburi, Thailand
[2]Technology Leamchabang College, Chonburi, Thailand
E-mail: jakkrit.kun@kmutt.ac.th, tirasak.sap@kmutt.ac.th, mongkol.kon@kmutt.ac.th, cherdchai.pra@kmutt.ac.th, piyasawat.nav@kmutt.ac.th, ekkachai.muj@kmutt.ac.th, and sampast.bo@tlc.ac.th

***Abstract* - This paper presents an implementation of a Wireless Internet of Things (IoT) system applied to the traction motor drive condition monitoring in electric vehicles (EVs). The design and testing of the prototype using an ESP8266 microcontroller module to acquire motor's vibration, current, and temperature information for the motor condition monitoring application is presented. This IoT system has been designed and developed from the ground up using commercially off-the-shelf components and open-source software platform for fast, reliable data acquisitions, low power consumption, and data gathered by the IoT system get reported to the cloud server in real time. The experimental results reveal that the IoT system is capable of capturing and reporting vital motor's parameters to cloud server and an automatic notification is sent to operators when motor's abnormality is detected in real time. Thanks to IoT technology, the preventive maintenance of traction motor can be effectively and remotely planned with rich data collection and analysis. With advanced power consumption reduction techniques, a sensor node consumes extremely low amount of battery power at which ideal for mobile applications.**

I. Introduction

Traction motor drive system is an essential and critical component for an electric vehicles (EVs). The traction motor must be efficient and reliable as it is required to provide both speed and torque in wide operating range while maintaining precise control of the motor drive safely [1]. To prevent the traction motor's abnormalities, improved reliabilities and effective operation with an early warning with instant notification is desirable and motor's vibration, current and temperature are practically three parameters that are well studied and widely accepted in detecting motor's failures due to electrical and mechanical faults [2]. According to the survey done by Institution of Electrical and Electronic Engineer (IEEE) [3], 44% of motor's faults are from bearing and 24% are from stator. The majority of mechanical failures in motor are mechanical imbalance, rolling and bearings because a continuous stress on them can result in the major failure. Factors such as improper lubrication, improper installation, contamination and corrosion often contributed into rolling and bearings faults. A vibration sensor and current sensor are able to detect motor's rough running of bearing increasing vibration and unbalance shaft current due to the flux disturbance caused by rotor eccentricities. Bearing failure also causes temperature rise to exceed motor's predetermined load temperature [4]-[5]. Our proposed wireless Internet of Things (IoT) sensor node is capable of integrating these active sensors and transmit data to the internet in real time with minimal power required. Compared with wired system, IoT system offers many advantages such as relatively low cost, ease of installation, remote upgradeable software, and automate real-time data analysis and warning notifications to operators. In addition, the preventive maintenance of traction motor can be effectively and remotely planned at the right time with rich data collection and analysis. It is changed from time-based or run-based maintenance to on-line predictive maintenance. The main benefits are such as cost reduction of maintenance, increased reliability, optimized traction motor performance, and improvement of accuracy in failure prediction.

This paper presents a development and implementation of a wireless IoT traction motor drive condition monitoring system based on ESP8266, a low-cost, low power with full TCP/IP stack and microcontroller produced by Espressif Systems [6]. The vibration, temperature, and current are sensed by ADXL345 acceleration, DS18B20 water proof metal casing temperature probe, and ACS712 current sensors, respectively. Information gathered by ESP8266 is then transmitted to cloud based server over the internet. Node-Red cloud-based software platform [7] collects, manages and analyzes data in real time and as motor's faulty is detected, the system automatically notifies operators about motor's condition instantly.

II. Traction Motor Condition Monitoring

Mostly, the traction motor can be selected as induction motor or permanent magnet synchronous motor (PMSM). Main faults of these two kinds of motors can be listed as follows:

- Stator faults such as shorted one or more phase windings, shorted inter-turn winding, etc.
- Rotor faults such as broken rotor bar or cracked rotor end rings, as well as shorted rotor field windings, etc.
- Static and/or dynamic air-gap irregularities or rotor eccentricities.
- Mechanical faults such as bearing and gearbox.

978-1-5090-2364-6/17/$31.00 ©2017 IEEE

As a result, the practical condition monitoring techniques for diagnosing these various faults of traction motor in real time are generally as follows:

- Vibration monitoring for conditions of bearing, gearbox, rotor eccentricity, etc.
- Temperature monitoring for conditions of bearing, winding insulation, etc.
- Current monitoring for conditions of stator and rotor winding, bearing, etc.

In this paper, the induction motor is focused on its condition monitoring in EVs. Three types of sensors for measuring the vibration, temperature, and current are practically proposed for condition monitoring in real time. Because these three basic sensors can be easily attached or installed with traction motor. Other kinds of sensors such as acoustic noise sensor, magnetic flux sensor, and etc are difficult to be installed as well as highly influential from the disturbing environment of traction motor in EVs, affecting their measurement accuracies.

III. A Wireless IoT Node-Red Cloud-Based Platform For Traction Motor Condition Monitoring

The traction motor with the proposed wireless Internet of Things (IoT) sensor node for traction motor condition monitoring system is shown in Figs.1 and 2.

Fig.1 Motors and load setup

Fig. 2 Sensors and inverters setup

The three-axis accelerometer (ADXL345) is used to measure the vibration while the current sensor (ACS712) is used to measure current and temperature sensor probe (DS18B20) is used to measure temperature of the motor housing or in bearing areas. All three sensors are connected to an ESP8266 IoT Wi-Fi chip powered by a small Lithium-ion battery in system diagram illustrated in Fig. 3. An ESP8266 is a single-chip device build-in 4MB of flash memory capable of connecting to the internet through build-in Wi-Fi (IEEE 802.11 b/g/n) module. The chip is small, low cost, low power and able to make TCP/IP connections using simple Hayes-style commands, making it perfect for wireless battery-powered applications. There are 16 general purpose input/output (GPIO) pins available on board which is more than enough for our application. The chip's processor is based on Tensilica Xtensa LX106 architecture running at the clock speed of 80 MHz provide processing power and GPIO sampling rate up to 10 kHz while the power consumption can be configured to 10 µA. Fig. 4 shows an open source Node-red cloud-based software platform developed by IBM Emerging Technology and the company contributed the software as open source under JS Foundation project in 2016 [8]. Node-red is a browser-based software tool for connecting hardware devices, application program interface (API) and many other software or on-line services as part of the IoT standard platform. Node-red runtime is built on node.js and JavaScript function is used for creating flows which are stored using JSON. The proposed system received data from sensor nodes over the internet then collected, managed and analyzed data into profiles in Node-red cloud database. These profiles are then compared with pre-existing normal operation profile. Any motor's abnormality detection is then flagged then sent to operator notification module which has a great flexibility due to numerous community-modules available in Node-red platform. These modules provide many standard notification tools such as e-mail, SMS as well as ever more popular social network channels including Facebook, Tweeter, Instagram, IFTTT and Line messaging.

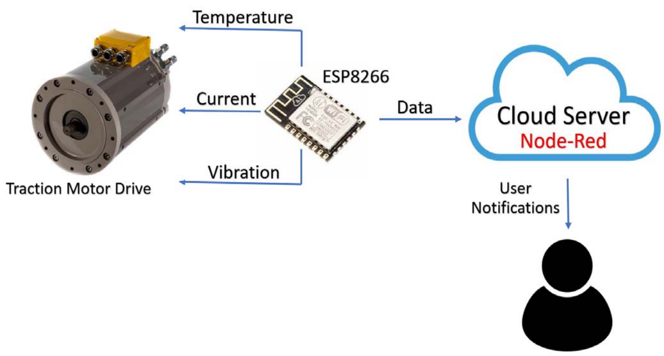

Fig. 3 An ESP8266 IoT based chip connect to a temperature, current and vibration sensors and transmit data to a Node-Red cloud server

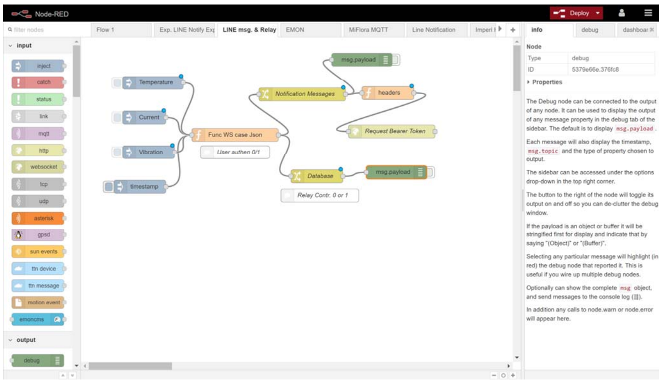

Fig. 4 An open source Node-red cloud-based software platform

IV. EXPERIMENTAL RESULTS

The proposed wireless Internet of Things (IoT) sensor node and Node-Red cloud-based platform for traction motor condition monitoring system are performed to verify measurement sensitivities, system's battery endurance, data communication reliability between a sensor node and the Node-Red cloud-base server, efficiency of the data management, analysis, and operator notification modules.

A. Temperature measurements results

The temperature sensor is able to detect an abnormal increase in traction motor's temperature with the resolution of one tenths of a degree Celsius. As we placed DS18B20 temperature sensor on motor's casing as well as motor front and rear ball baring areas, as the normal motor perform with load will see that the temperature rise slowly and level off around 69.5 degree Celsius. When compared to a motor with front faulty ball bearing, the temperature raised much faster and the temperature level of at higher value as shown in Fig. 5. A thermal imager (Fluke Ti95) was used to verify the heat level at motor's casing and font ball bearing areas as shown in Figs. 6 and 7. The temperature values measured by the thermal imager agreed with the measurement results performed by our temperature sensors as expected.

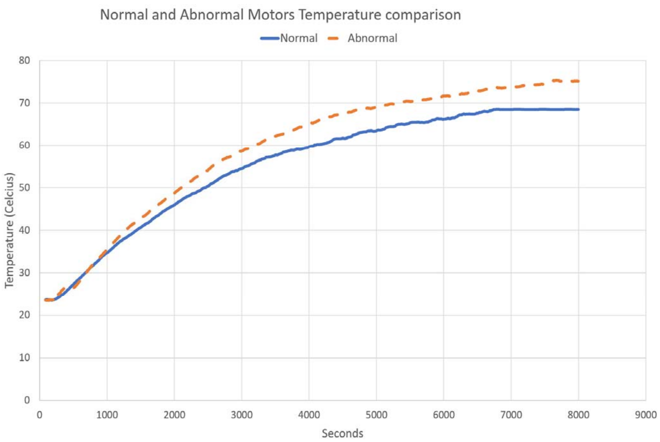

Fig. 5 Motor's temperature comparison between normal and abnormal units

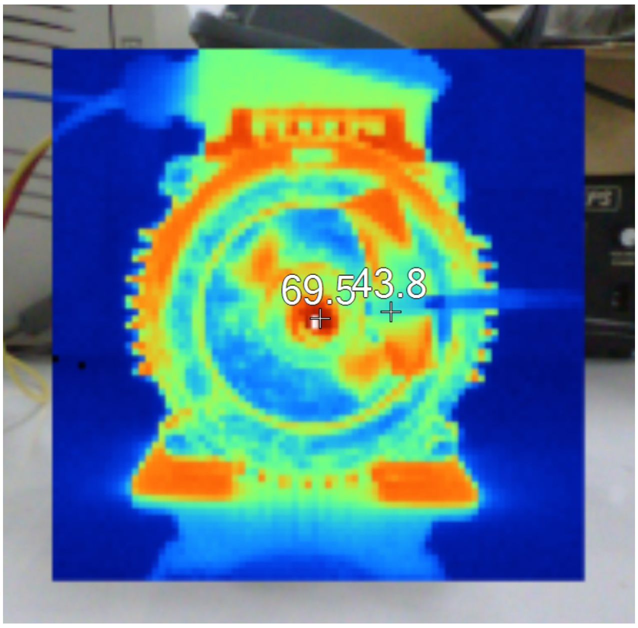

Fig. 6 Normal motor with temperature at the front ball baring around 69.5 degrees Celsius

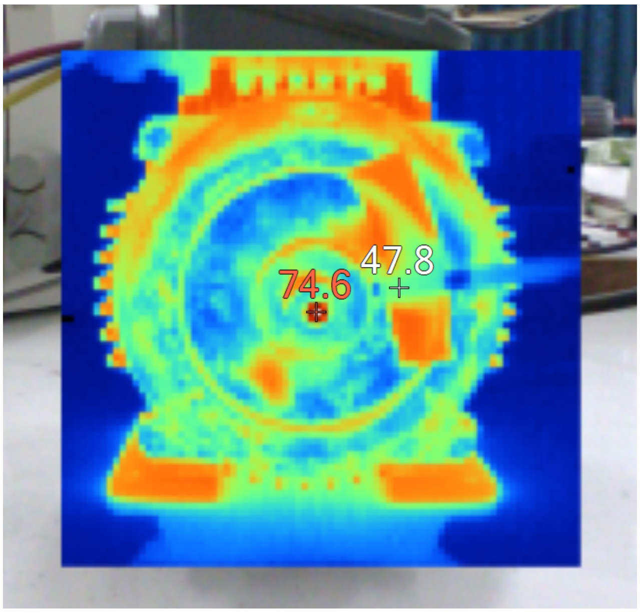

Fig. 7 Faulty motor with temperature at the front ball bearing around 74.6 degrees Celsius

B. Vibration measurements results

The vibration sensor is sufficiently sensitive and the sensor node sampling rate is fast enough to detect frequencies that are potentially harmful to the motor's operation. The sampling rate used in measuring motor's vibration is approximately 8 kHz. This is the maximum sampling frequency of the ESP8266 analog to digital sampling frequency limit without any special technique to push the chip's sampling rate higher but at the expense of scarifying some chip's stability [6].

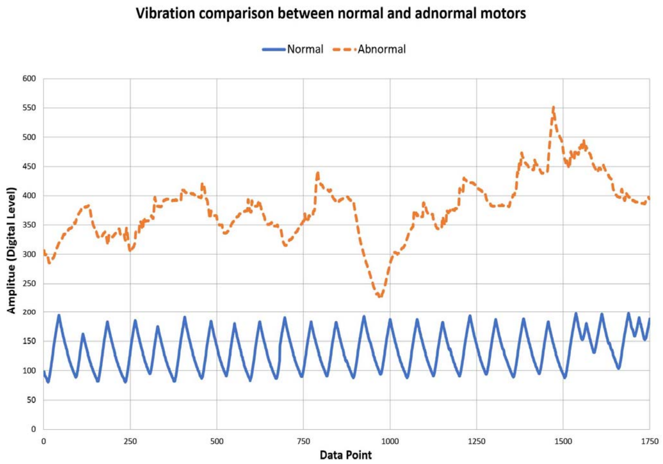

Fig. 8 Motor's vibration comparison between normal and abnormal units

C. Current measurements results

Current variations and spike are detected by the sensor node and data gather were also successfully recorded by the Node-red server. Fig. 9 presents the currents measured by our sensors between normal and faulty motors. There are small but noticeable deviations between normal and faulty motors due to small rotor misalignments used in this experiment. As the motor rotor misalignments or bearing faulty become more severe, larger current is expected. In other words, the higher sensitivity of mechanical fault detection is likely dependent on the vibration and temperature variations. However, the current consumed by the motor in the case of stator faults such as shorted one or more phase windings, shorted inter-turn winding is much larger as compare to normal working motor.

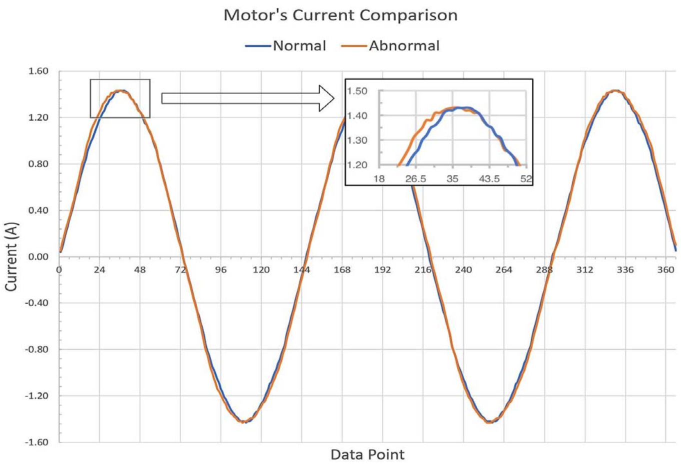

Fig. 9 Motor's current consumption comparison between normal and abnormal units

The results also show that two rechargeable batteries are able to power a sensor node with three sensors attached over 30 days of continuous operation with regular updating intervals to the internet. Since the ESP8266 is programmed into the deep-sleep mode most of the time. The chip's deep-sleep mode will not require the constant WIFI connection. In fact, for this system, the chip's transition interval is set to 300 seconds while checking sensors such as temperature every 100 seconds. Normally, the chip is waking up from the deep-sleep mode and connecting to Access Point (AP) required approximately from 0.3 to 1 second. The overall current consumption of this system configuration can be calculated in the below equation (1) [6].

$$\begin{aligned} &Deep-Sleep \\ &I = I_{deep\_sleep} + \frac{20mA \times 100ms_{(wakeup)} + I_{RX} \times 1s + I_{TX} \times 0.1s}{300s} \\ &= 10uA + \frac{20mA \times 100ms_{(wakeup)} + 70mA \times 1s + 200mA \times 0.1s}{300s} \\ &\approx 0.3mA \end{aligned} \tag{1}$$

According to this calculation, the chip's overall power consumption per hour is approximately 0.3 mA. Together with all sensors, this puts the power budget of the system to less than 1 mA per hour.

Table 1 present the current consumption of the ESP8266 IoT chip in many normal operation modes in IEEE 802.11b, g, and n standards as well as three low power modes including light-sleep, modem-sleep and deep-sleep modes. Depending upon application requirements low power modes are most desirable operation modes due to its extremely attractive low power consumption on the chip offered.

Table. 1 Current consumption by the ESP8266 [6]

Parameter	Typical	Unit
Tx 802.11b, CCK 11Mbps, P_{OUT}=+17dBm	170	mA
Tx 802.11g, OFDM 54Mbps, P_{OUT} =+15dBm	140	mA
Tx 802.11n, MCS7, P_{OUT} =+13dBm	120	mA
Rx 802.11b, 1024 bytes packet length , -80dBm	50	mA
Rx 802.11g, 1024 bytes packet length, -70dBm	56	mA
Rx 802.11n, 1024 bytes packet length, -65dBm	56	mA
Modem-Sleep	15	mA
Light-Sleep	0.5	mA
Power save mode DTIM 1	1.2	mA
Power save mode DTIM 3	0.9	mA
Deep-Sleep	10	uA
Power OFF	0.5	uA

The sensor node is able to transmit data packages up to 97% successful rate to the Node-red cloud based internet at the distance between IoT-based sensor and receiver over 30 meters. This is an impressive distance as compared to the existing wire-based monitoring system. A notification module utilizes low processing power but consumes relatively high current consumption when transmitting data as shown in Table 1. A pre-determined predictive messaging interval of the sensed temperature, current and vibration values is sent to the server and then Node-Red runtime analyzes data message before sending the appropriate notifications to the operators.

The notifications latency is normally less than 1 second over free-social network-services such Facebook, Tweeter, IFTTT or Line messaging and usually even less with paid service such as SMS.

V. CONCLUSION

This paper presented the software and hardware designs and measurement results of a wireless IoT-based system and notifications applied to the traction motor drive condition monitoring in electric vehicles (EVs). Temperature, current and vibrations signals have been analyzed to predict any mechanical abnormality such as motor's faulty ball bearing and rotor imbalanced or cracked. Signals gathered by our IoT-based sensors were fed into the cloud-based server analyzed by Node-Red and determined motor's health condition or severity level. Analytical information provided by the system is a crucial part of effective predictive maintenance which translates into more effective maintenance services and much lower operational cost over the motor's lifetime. The prototype of wireless IoT-based motor health monitoring system has been successfully implemented. The mechanical abnormality of motor can be predicted at the early stage. The proposed system is operated satisfactorily and possibly adopted in the future EVs due to its size, operational duration, and flexibility of wireless IoT-based smart features.

REFERENCES

[1] K. M. Siddiqui, K. Sahay, V. K. Giri, "Health Monitoring and Fault Diagnosis in Induction Motor- A Review", International Journal of Advanced Research in Electrical, Electronic and Instrumentation Engineering, Vol. 3, Issue. 1, 2014.

[2] L. Hou, N. W. Bergmann, "Novel Industrial Wireless Sensor Networks for Machine Condition Monitoring and Fault Diagnosis", IEEE Transaction on Instrumentation and Measurement, Vol. 61, No. 10, 2012.

[3] S. Korkua, H. Jain, W. Lee, C. Kwan, "Wireless Health Monitoring System for Vibration Detection of Induction Motors", IEEE Industrial and Commercial Power Systems TeAchnical Conference(I&CPS), 2010.

[4] C. M. Leung, S. W. Or, S. L. Ho, K. Y. Lee, "Wireless Condition Monitoring of Train Traction Systems Using Magnetoelectric Passive Current Sensors", IEEE Sensors Journal, Vol. 14, No. 12, 2014.

[5] A. Chater, "Traction Motor In-Service Multi-Technology Condition Monitoring", IET Railway Condition Monitoring conference, 2008.

[6] Espressif Systems, "Official SDK release from Espressif for ESP8266". Espressif. *July 2015.*

[7] K. Antevski, A. E. Redondi, R. Pitic, "A hybrid BLE and Wi-Fi localization system for the creation of study groups in smart libraries", IFIP Wireless and Mobile Networking conference (WMNC), 2016.

[8] G. Petrovie, V. Dimitrieski, H. Fujita, "Cloud-based Health Monitoring System Based on Commercial Off-the-Shelf Hardware", IEEE Internal Conference on Systems, Man, and Cybemetics SMC, 2016.