Histogram-based of Healthy and Unhealthy Bearing Monitoring in Induction Motor by Using Thermal Camera

Norliana Khamisan, Kamarul Hawari Ghazali, Ali Almisreb and Aufa Huda Muhammad Zin
Applied Electronic and Computer Engineering (AppECE),
Faculty of Electrical and Electronic Engineering, Universiti Malaysia Pahang, 26600 Pekan Pahang
norlianakhamisan@gmail.com

***Abstract*—Nowadays, it is a crucial to develop a monitoring system to detect faulties in machines as it helps to prevent high maintenance costs, prolong the lifetime of the machines as well as prevent production lost. This study has been motivated by the increasing number of machine failure, which has become an oustanding issue in the industries. In this study, infrared thermal camera has been employed as an instrument to identify and analyze thermal anomalies, so that the information of the machine condition can be analyzed effectively. Infrared thermal camera is one of the most efficient testing approaches and it is known as non-destructive technique for fast detection. This paper also discussed a review of the previous work regarding the different thermal imaging approach for induction motor fault detection. In this work, Histogram-based approach was used to classify the healthy and unhealthy bearing variation temperature behavior of a three-phase induction motor. Eventually, the analysis of the work explained that the potential to monitor the element bearing by utilizing infrared thermal camera has proven effectively. It is concluded that this is an excellent instrument to differentiate the healthy and unhealthy bearings.**

***Index Terms*—Thermal Camera; Condition Monitoring; Bearing Induction Motor; Healthy and Faulty.**

I. INTRODUCTION

Developing systems that diagnose machines malfunction is challenging due to its important role in the industrial fields,. Considering that a bad manufacturing machine can affect productivity, quality and cost for the industry, a system that diagnoses the machine malfunction helps to preclude sudden breakdown, minimize downtime, reduce preventive maintenance cost, and extend the lifetime of the machines. Before the motor component is damaged, measures and investigation of early detection is very important in the machinery system. The sooner these faults are detected, the more affordable they are to remedy the problems; hence, the possibility of unforeseen downtime is enormously decreased.

The methods for diagnosis the motor condition either normal or fault consist of two parts: the fault/ normal detection and the fault diagnosis (as shown in Figure 1). For the fault/normal recognition part, it evaluates the thermal images pattern, which subsequently generates features as the input for fault diagnosis part. This fault diagnosis process is evaluated by classification process to determine and differentiate fault type whether the bearing motor is in healthy or unhealthy condition.

The three phase AC induction motor named Squirrel cage, is the most widely used in industrial, domestic and commercial due to their load bearing capacity as well as their key features, such are high realibity, simple, low cost, minimum maintenance and high efficiency.

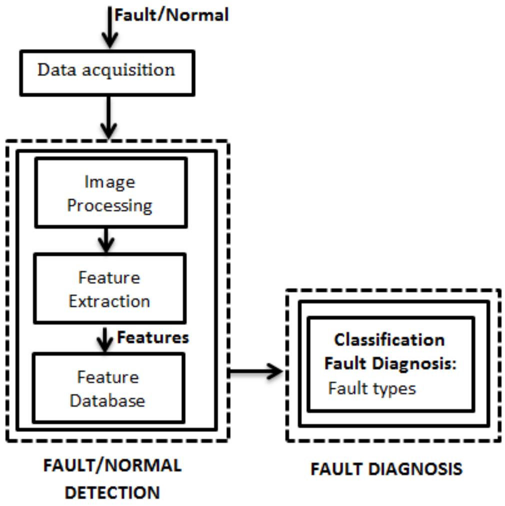


Figure 1: Methods for diagnosis the bearing motor condition

Meanwhile, by utilizing a different type of sensors in motor monitoring system, it will monitor the physical state sign of the motor. By doing so, a few fault conditions can be recognized such as stator windings, bearing faults, rotor bars, shaft damage, external devices, gearbox faults, misalignment, and short rotor field winding [1] [2]. Based on studies by Thomson, W.T. & Fenger from the Electric Power Research Institute, the most common fault occurrences of induction motors are the bearing faults and stator faults [3-5]. In fact, in [6], it demonstrated that over 40% of this bearing related problems are among the most common causes of motor failures. This notifies that bearing components are one of the crucial part inside the induction motor. Hence, observing the state of this bearing is imperative to prevent any fault and damage. There are many types of monitoring techniques utilized for induction motor in order to distinguish some faults for instance, electromagnetic field monitoring, RF emission monitoring, motor current signature analysis monitoring (MCSA), infrared detection, temperature monotoring, vibration measurements, chemical analysis monitoring, acoustic monitoring, artificial intelligence, neural network techniques and shock pulse method (SPM) [2, 7].

II. THERMAL IMAGING SYSTEM

Temperature is one of the important signs that should be viewed to enhance mechanized condition monitoring throughout the conduct of the monitoring. Thus, in a few years, infrared thermal camera approach has been applied as another new approach in the monitoring for fault diagnosis. This is due to its fast discovery of the potential issues or defects that helps to diminish the investigating time and precaution maintenance. Besides, this thermal cameras offer an extremely secure non-contact investigations; hence, reducing the need for predictive maintenance teams to put themselves in a damaging condition when performing an investigation. In this analysis, thermal camera named as A615 FLIR has been utilized as a device that has IR resolution 640 x 480 pixels for capturing the thermal radiation pattern behavior on bearing motor fault. The range of this thermal camera can offer until 640x480 pixels, equivalent to 307, 200 measurement spots. Besides, this tool also can specify the temperature of the object through its operating condition to detect any faults from the object measured.

Infrared camera will not be able to quantify the temperature of the machine's body straightforwardly. This is due to the luminance emitted from an object measured taken by this thermal camera will make it very sensitive. At the same time, a number of black body radiation would be released by the object measured as a function for their temperatures. Generally, the more infrared radiation is emitted as black-body radiation. It indicates that the object's temperature being measured is high. In thermal radiation hypothesis, blackbody is considered as a theoretical item which ingests every single occurrence radiation and transmits a continuous range as indicated by Planks's law, as shown below:

$$I(v,T) = \left[2 * h * v^3 / c^2\right]\left[1/\left(e^{h*v/k*T} - 1\right)\right] \quad (1)$$

where: $I(v,T)$ = Spectral radiance
h = Constant of Plank
c = Light speed in vacuum
k = Constant of Boltzmann
v = Electromagnetic radiation frequency
T = Body temperature (Absolute temperature)

$$j* = (\sigma) * (T^4) \quad (2)$$

where: $j*$ = Sum of power radiated per unit area
T = Temperature (Absolute temperature)
$\sigma = 5.67x10^{-8} Wm^{-2} K^{-4}$ (constant of Stefan-Boltzmann)

III. LITERATURE REVIEW

A few research works by utilizing thermal imaging monitoring system have been made with induction motor bearing fault detection [8-15] and herein, there are varieties of proposed methods that have been published. This infrared thermal camera approach has also been widely used in various areas, for example in power generation, electrical application, mechanical application, skin lesion and agriculture [16-25]. This approach will be conducted automatically and it does not require expertise to observe the thermogram produced. The attention of past research has been on the recognition of motor condition, such are misalignment on motor shaft, mass unbalance and defects on the bearing. Subsequently, in order to recognize these conditions, a development processing of image technique and steps on learning the machinery system are implemented.

According to Ali Md. Younus et al. [9], two methods named as Principle Component Analysis and Independent Component Analysis have been utilized in their work as extraction tools due to the large dimensionality parameters extracted from the raw thermal data. ARTKNN and PPNN were implemented in this work to diagnose several conditions of faulty machine. Another work [15], a technique called DWT has been resolved for the extraction process to seek the machine features. Subsequently, to select the significant features of the machine, a technique called MD, which is Mahalanobis Distance as well as RA, which is Relief Algorithm techniques were developed in order to enhance a performance of classifier state; there are SVM and LDA classifiers. A technique called bi-directional empirical mode decomposition (BEMD) have been reported by Van Tung Tran et al. [13]. This method has been used as image enhancement in order to evade the overlapping during the reduction process is carried out. In their work, the study on comparison of classification results was also carried out for model accuracy evaluation between RVM, SVM and ANFIS techniques. Next, in [8], the development of intelligent maintenance system by using self-organizing map (SOM) has been proposed in order to find a new machine diagnostics technique and a new alternative source feature. Yet, in this research work, vibration signal and thermal image were presented as the experiment data. K-Means clustering approach and Otsu's method thresholding have been used in image processing process to generate extracted features. These features then were used as input data for thermal image to be utilized in SOM training and were compared with input from vibration data. Subsequently, the accuracy showed good performance for both testing thermal and vibration data. In another work in [11], a method called object matching technique was implemented to produce the pattern recognition process in infrared images. In their work, scale invariant feature transform, SIFT algorithm was conducted to extract the number of interest point from train and target image. Herein, to investigate the type of damage in the motor, mean features of object's part were fed to a classifier. The C4.5 tree algorithm and the Naïve bayes algorithm have been utilized as a classification technique to denote the performance of the system by looking on their accuracy value. Next, an approach to observe or pinpoint the temperature value on any body motor surface during the operation of the motor using infrared thermography also has been proposed. In their work, they explained that the importance of the motor temperature measurements depends on the influence of measured values of the parameters value [26].

Besides, thermal imaging technique also has been used in several researches to prove the different thermal pattern characteristics of healthy and faulty components in induction motor such as bearing, body of the motor and fan failure [27-29]. In their work, they have proven that the capability to utilize the infrared thermography tools could be an important tool for monitoring the condition of the motor since these tools are able to predict the thermal behavior whether the motor is in the state of healthy or unhealthy. Herein, several of the descriptive details as described above have been summarized in Table 1.

IV. EXPERIMENT SETUP AND RESULT

In this paper, condition monitoring on bearing fault diagnostics of induction motor using the thermal camera has implemented and all thermogram data have been collected. The thermal monitoring of the bearing is divided into two states. The first state is the healthy bearing, while the second state is called unhealthy bearing. To fulfil the experiment requirement, other related parameters to motor operation such are speed, voltage and current were also recorded. As illustration in Figure 2, FLIR A615 thermal camera with long wave IR camera sensor type has been utilized in this work to monitor the bearing motor state and the distance measured from the object's position is within 0.5m

Figure 2: Experimental setup using thermal camera

In this work, 415V, 1-hp and three phase induction motor device was utilized to measure the condition of the bearing motor and the specification maximum rated current value for this induction motor is 1.8Ampere. Initially, the speed motor value that has been conducted in the experiment is equivalent to 1280rpm. Prior to that, to make the condition of the motor stable and to generate the initial heat in the bearing, the speed was first carried out for five minutes.

As shown in Figure 3, the small part of the three-phase induction motor conditions that indicates the bearing surface to be analyzed are located in the middle of the coupling between the motor and the load part.

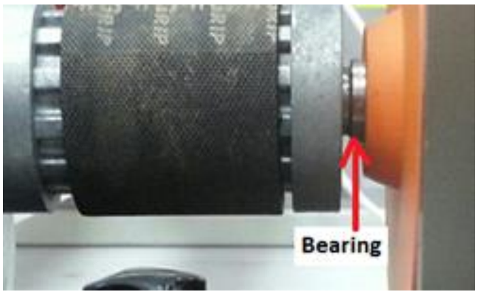
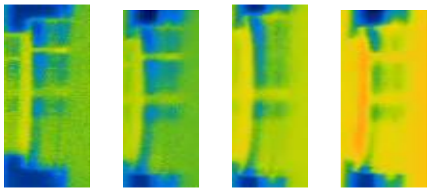


Figure 3: Bearing of three phase induction motor

In this experiment, the healthy thermogram of the bearing motor are acquired first at different load conditions and it has three states of current value that continuous running from one time to another: They are i) I1=0.55Amp (Torque1=0.2N-m) that generates 601 thermal images, ii) I2=0.8Amp (Torque2=0.4N-m) that generates 563 thermal images and iii) I3=1.8Amp (Torque3=0.8N-m) that generates 817 thermal images. At these time, the conditions of motor are in normal state. To acquire the infrared thermal image of bearing fault, overload condition was created manually by increasing the input current to reach over the rated current, which is 2.0Ampere (Torque=1. 0N-m) that generates 612 thermal images. By doing so, different thermal behaviors on bearing are clearly observed and there are denoted in Figure 4. Subsequently, the acquired data were analyzed by Matlab software that has been stored in a Personal computer (PC).



(a) (b) (c) (d)

Figure 4: (a) Normal current, I1=0.55Amp (601 images), (b) Normal current, I2=0.8Amp (563 images), (c) Normal current, I3=1.8Amp (817 images), (d) Abnormal current, I=2.0Amp (612 images)

As indicated by Stefan-Boltzmann Law, it clarifies that more energy will be emitted, when an object gets hotter. This means that , as the object molecules increase, the higher the temperature value will be produced in this thermal imaging application system. Yet, by using the thermal color palette, brighter and whiter color represents higher temperatures, while the darker color represents the colder temperatures. This has been proved from Figure 4 which shows that the higher the value of current during the motor rotates, the higher the temperature reading will be generated. The changing color of the bearing can be seen in Figure 4(a), (b), (c) and (d), where the higher temperature value of the bearing is presented by the brighter color.

Figure 5 indicates the image histogram-based pattern that provides information about the characteristic of the grayscale color distribution under three states ranging from the healthy bearing condition to the unhealthy bearing condition motor as image with x-axis represents the color intensity and y-axis represents the pixel value. The graph also reveals that as the load in the machine increases, the heat (temperature) will increase, respectively. Afterwards, it is also explained that blue color denotes the lowest temperature followed by yellow color and pink color. Meanwhile, the highest level of temperature is marked by red color which is extracted from an abnormal current bearing condition.

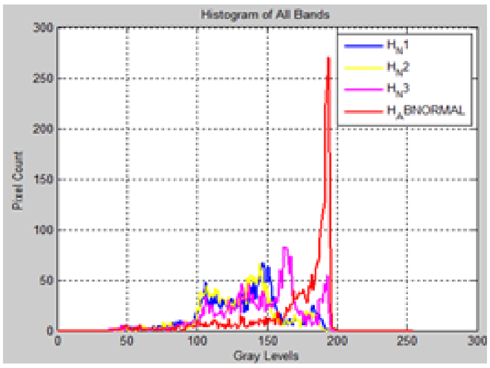
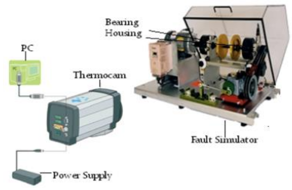
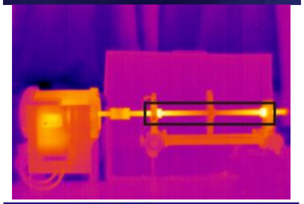
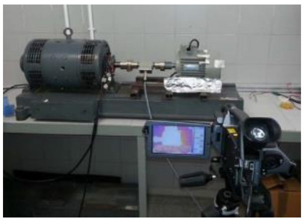
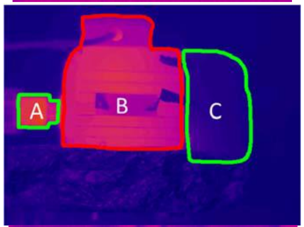
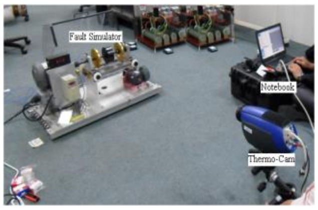
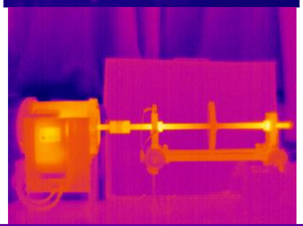
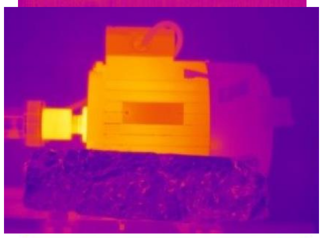
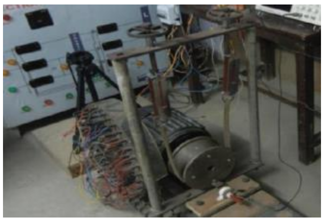
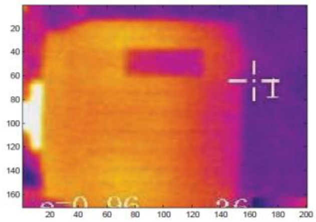
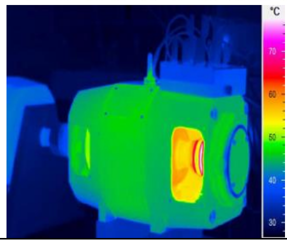


Figure 5: Histogram-based of the normal thermal pattern and abnormal thermal pattern of bearing motor

Table 1
Experimental Setup of the Previous Research

Authors	Specification of thermal camera	Experimental motor setup	Real time experimental setup	Thermogram
Achmad Widodo et al. (2012) [8]	-Thermal camera FLIR SC5000	-Fault simulator, image acquisition produces 30images persecond,machine operated at 1800rpm		
Ali Md. Younus et al. (2009) [9] [10]	-Thermal camera FLIR-A 40 series with long wave sensor -Thermal Sensitivity (0.08°C at 30°C)	-Fault simulator, Diameter of shaft 30mm, 2 ball bearings, 2 bearing housing		
Petros Karvelis et al. (2014) [11]	-Thermal camera FLIR S65 series & High sensitivity long wave	-1.1 kW induction motor		
Van Tung Tran et al. (2013) [13]	-Thermal camera FLIR-A 40 series with long wave sensor -Thermal Sensitivity (0.08°C at 30°C)	-Fault simulator, Diameter of shaft 30mm, 2 ball bearings, 2 bearing housing, 480 features value extracted from ROIs (80x6)		
M.J. Picazo-Rodenas et al (2015) [28]	-Thermal camera FLIR S65 Series & High sensitivity long wave	-1.1 kW IM,rated current 2.7(Y)/4.6(Δ), Rated voltage 400(Y)/230(Δ), rated speed (1410 rpm)		
D.K.Chaturvedi et al. (2015) [27]	-Thermal camera (uncoiled FPA microbolometer) -sensitivity of thermal 0.1°C @ 30°C	-Squirrel cage induction motor three phase (230V, 50Hz, 3 HP)		
J. G. Fantidis et al. (2013) [26]	- Thermal Jenoptik camera VarioCAM® 7800 -Resolution of 640×480 pixels	- slip-ring motor 3-phase TERCO 1007–695 -power 1.1kW, speed 1440rpm		

V. Conclusion

In this paper, the potential of thermal imaging for monitoring rolling element bearing has been proposed on both the healthy and unhealthy condition. The different thermal image processing techniques and the experimental setup from the previous researchers were discussed also. A method called gray level histogram was introduced to identify the normal and abnormal variation temperature of the three-phase bearing induction motor. From the result validation analysis, it can be confirmed that the infrared thermal camera can monitor and classify the different behavior of thermal pattern between the healthy and unhealthy bearing. Thus, image processing analysis will be implemented in the next stage in order to develop bearing fault monitoring system automatically for the healthy and faulty condition.

ACKNOWLEDGEMENT

We would like to express our gratitude to the Postgraduate Research Grant Scheme (PGRS) of the Faculty of Electrical and Electronics Engineering (FKEE), Universiti Malaysia Pahang (UMP) for the financial support granted.

REFERENCES

[1] Thorsen, O.V. and M. Dalva, *A survey of faults on induction motors in offshore oil industry, petrochemical industry, gas terminals, and oil refineries.* Industry Applications, IEEE Transactions on, 1995. **31**(5): p. 1186-1196.

[2] Nandi, S., H.A. Toliyat, and L. Xiaodong, *Condition monitoring and fault diagnosis of electrical motors-a review.* Energy Conversion, IEEE Transactions on, 2005. 20(4): p. 719-729.

[3] *IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.* ANSI/IEEE Std 493-1980, 1988: p. 3.

[4] Albrecht, P.F., et al., *Assessment of the Reliability of Motors in Utility Applications - Updated.* Energy Conversion, IEEE Transactions on, 1986. EC-1(1): p. 39-46.

[5] Thomson, W.T. and M. Fenger, *Current signature analysis to detect induction motor faults.* Industry Applications Magazine, IEEE, 2001. **7**(4): p. 26-34.

[6] Schoen, R.R., et al., *Motor bearing damage detection using stator current monitoring.* Industry Applications, IEEE Transactions on, 1995. **31**(6): p. 1274-1279.

[7] Hulugappaa, B., T. Pasha, and K. M Ramakrishna, *Condition Monitoring of Induction Motor Ball Bearing Using Monitoring Techniques.* International Journal of Information Technology & Computer Sciences Perspectives, 2013. **2**(1): p. 281-287.

[8] Achmad Widodo, D.S., Toni Prahasto, Gang-Min Lim,Byeong-Keun Choi, *Confirmation of Thermal Images and Vibration Signals for Intelligent Machine Fault Diagnostics.* international Journal of Rotating Machinery, 2012. 2012.

[9] Ali Md. Younus, A.W., Bo-Suk Yang, *Application Of Thermal Image: Machine Fault Diagnosis Using Pca And Ica Combine With Svm.* 2009.

[10] Ali Md. Younus, K.A., Bo-Suk Yang, *Wavelet Co-Efficient of thermal image analysis for machine fault diagnosis.* 2009.

[11] Karvelis, P., et al. *An automated thermographic image segmentation method for induction motor fault diagnosis*. in *Industrial Electronics Society, IECON 2014 - 40th Annual Conference of the IEEE*. 2014.

[12] Khamisan, N., K.H. Ghazali, and A.H.M. Zin, *A Thermograph Image Extraction Based On Color Features For Induction Motor Bearing Fault Diagnosis Monitoring.* 2015.

[13] Tran, V.T., et al., *Thermal image enhancement using bi-dimensional empirical mode decomposition in combination with relevance vector machine for rotating machinery fault diagnosis.* Mechanical Systems and Signal Processing, 2013. **38**(2): p. 601-614.

[14] Younus, A.M. and Y. Bo-Suk. *Wavelet co-efficient of thermal image analysis for machine fault diagnosis*. in *Prognostics and Health Management Conference, 2010. PHM '10.* 2010.

[15] Younus, A.M.D. and B.-S. Yang, *Intelligent fault diagnosis of rotating machinery using infrared thermal image*. Expert Systems with Applications, 2012. **39**(2): p. 2082-2091.

[16] Kamaruddin, S., et al. *Canned Pineapple Grading Using Pixel Color Extraction*. in *Proc. The International Conference on Artificial Intelligence in Computer Science and ICT (AICS 2013)*.

[17] Cetingul, M.P. and C. Herman. *Identification of skin lesions from the transient thermal response using infrared imaging technique*. in *Biomedical Imaging: From Nano to Macro, 2008. ISBI 2008. 5th IEEE International Symposium on*. 2008.

[18] Ying-Chieh, C. and Y. Leehter. *Automatic Diagnostic System of Electrical Equipment Using Infrared Thermography*. in *Soft Computing and Pattern Recognition, 2009. SOCPAR '09. International Conference of*. 2009.

[19] Bortoni, E.C., R.T. Siniscalchi, and J.A. Jardini. *Hydro generator efficiency assessment using infrared thermal imaging techniques*. in *Power and Energy Society General Meeting, 2010 IEEE*. 2010.

[20] Kolaric, D., et al. *Application of infrared thermal imaging in blade system temperature monitoring*. in *ELMAR, 2011 Proceedings*. 2011.

[21] Jadin, M.S., et al. *Finding ROIs in infrared image of electrical installation for qualitative thermal condition evaluation*. in *2012 IEEE International Conference on Control System, Computing and Engineering*. 2012.

[22] Garcia-Ramirez, A.G., et al. *Thermographic technique as a complement for MCSA in induction motor fault detection*. in *Electrical Machines (ICEM), 2014 International Conference on*. 2014.

[23] Huda, A.S.N., et al., *A new thermographic NDT for condition monitoring of electrical components using ANN with confidence level analysis.* ISA Transactions, 2014. **53**(3): p. 717-724.

[24] Jadin, M.S., K.H. Ghazali, and S. Taib. *Detecting ROIs in the thermal image of electrical installations*. in *2014 IEEE International Conference on Control System, Computing and Engineering (ICCSCE 2014)*. 2014.

[25] Jadin, M.S., S. Taib, and K.H. Ghazali, *Feature extraction and classification for detecting the thermal faults in electrical installations.* Measurement, 2014. **57**: p. 15-24.

[26] Fantidis, J., et al., *The study of the thermal profile of a three-phase motor under different conditions.* ARPN Journal of Engineering and Applied Sciences, 2013. **8**(11): p. 892-899.

[27] Chaturvedi, D., S. Iqbal, and M.P. Singh. *Intelligent health monitoring system for three phase induction motor using infrared thermal image*. in *Energy Economics and Environment (ICEEE), 2015 International Conference on*. 2015. IEEE.

[28] Picazo-Rodenas, M., R. Royo, and J. Antonino-Daviu, *A New Methodology for Complementary Diagnosis of Induction Motors Based on Infrared Thermography*. International Journal on Energy Conversion (IRECON), 2015. **3**(2): p. 44-52.

[29] Schulz, R., et al. *Thermal imaging for monitoring rolling element bearings*. in *12th International conference on Quantitative InfraRed Thermography (QIRT 2014)*. 2014