VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

A THERMOGRAPH IMAGE EXTRACTION BASED ON COLOR FEATURES FOR INDUCTION MOTOR BEARING FAULT DIAGNOSIS MONITORING

Norliana Khamisan, Kamarul Hawari Ghazali and Aufa Huda Muhammad Zin
Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia
E-Mail: norlianakhamisan@gmail.com

ABSTRACT

In this study, an approach of extraction analysis for bearing fault diagnosis of rotating machinery based on thermogram investigation using color features is proposed in this paper. This research was proposed since condition monitoring and motor failures are great concern in industries. Early fault detection in machineries can avoid production lost and reducing maintenance costs. Therefore, in this work, infrared thermography (IRT) is used as a tool to detect early sign for bearing fault since this infrared thermography (IRT) is one of the most effective non-destructive testing techniques of condition monitoring and fault diagnostics. By using this infrared thermography (IRT) technology, the information of machine condition can be analyzed. In the present study, 300 thermal images are used in this simulation process whereby the images are classified into two classes namely normal and abnormal. The first class consists of 150 images normal bearing while another 150 images denote abnormal bearing class. SURF feature-based algorithm, RGB color space and active contour segmentation are employed in this paper in order to process and differentiate between normal and abnormal bearing image by means of color features called statistical technique. The experiment results indicate that this statistical features of RGB color space able to distinguish the differences between normal and abnormal features of bearing in machinery system.

Keywords: Thermal imaging, SURF feature-based, RGB color space, active contour segmentation, statistical

INTRODUCTION

Condition monitoring of mechanical machinery or any component of a machine has become challenging and important task for the identification of different machine condition which can effect productivity, quality and cost for the industry. It is important as a way to avert sudden breakdown, minimize down-time, reduce maintenance cost, and extend the lifetime of machines. The use of conditional monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. The sooner these faults are detected, the cheaper they are to correct and the chance of unexpected downtime is greatly reduced.

Motor machinery such as induction motors are a critical component of many industrial processes. Safety, reliability, efficiency, and performance are some of the major concerns of induction motor applications. Major machine failures include stator faults, rotor faults, mechanical faults such as bearing damage and misalignment [1]. Bearing component is an important component and widely used in modern rotating machinery. Faults occurring in the bearing may lead to breakdowns of machines. As mentioned in [2], studies of motor reliability has made and was explained that 40% of all machine failures will occurred due to bearing problem in mechanical machinery. Different approaches have been developed over recent decades in order to diagnose machine condition monitoring. There are include type of sensors and non-sensor such as vibration sensors, acoustic emission sensors, temperature sensors, chemical analysis, sound pressure monitoring, current monitoring and other methods. In spite of that, these types of bearing condition monitoring have their own drawbacks [3].

In recent times, many researchers who concentrate to another new popular approach of condition monitoring and fault diagnostics which allows for quick detection of potential problems or defects that will reduce troubleshooting time and preventative maintenance. This approach technique is called infrared thermal imaging technique. With the advantages of this infrared thermal imaging tool, it has been considered as a new approach which can be applied for fault diagnosis due to this thermal cameras offer non-contact inspections that are extremely safe, reducing the need for predictive maintenance teams to put themselves in harm's way when performing an inspection. In this experiment, A615 FLIR type of thermal camera have been used as a hardware tool that has IR resolution 640 x 480 pixels for capture thermal radiation pattern on bearing motor fault. By using an infrared camera, it could be used to perform predictive maintenance within electrical and mechanical machinery allows hazardous and costly faults to be identified before they become more serious and expensive to repair. The range of this thermal camera can offer until 640x480 pixels, equivalent to 307, 200 measurement spots.

In contrast with other technologies, a thermal imaging camera forms an image using infrared radiation, which is similar to a common camera which forms images using visible light. In other words, it is a device that used to capture the infrared energy which transfers from an object to its environment and produce a real-time image in a color palette. This tool can be applies for fault diagnosis because of the possibility to indicate the object's operating condition through its temperature.

THERMAL IMAGE AND PREVIOUS WORK

Thermal imaging technique has been used in many applications such as in power generation, electrical equipment, skin lesion, induction motor fault detection, agriculture [4-10] and so on. There are varieties of proposed techniques of thermal imaging monitoring for motor bearings that have been previously published [11-17]. The analysis outputs of this thermal pattern were investigated by using image processing technique. This computing technology which is image processing technique has been widely used in the last decade and contributes in many applications such as in agriculture engineering, face detection, electrical inspection, thermal imaging, biomedical and car driver assisted [18-27]. This can greatly improve the effectiveness of the monitoring on motor fault condition. Generally, there are five (5) major stages in image processing technique including data acquisition, image pre-processing, image segmentation, feature extraction and classification technique. Based on the related previous literature reviews on the motor fault by using thermal image system, most of the researchers are using raw parameter IRT data that was extracted from the thermal data obtained without implement the segmentation process [12, 15-17]. Meanwhile, another one approach is, the segmentation process was implemented that has been proposed by [11, 14]. In the present study, image segmentation is implemented in order to process the partitioning the thermal image obtained. It was conducted to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze before led to feature extraction process.

METHODOLOGY

In this section, the proposed study consists of consequent procedures: Image acquisition, Image segmentation that was processed by SURF algorithm as well as active contour as a technique to enhance the segmented image and last procedure is image feature extraction that was conducted by statistical approach.

Image acquisition

The first task supposedly begins with the image acquisition process. Figure-1 below illustrates the experimental setups that were carried out by using thermographic camera FLIR A615 at a distance of 0.5m. The maximum rated current value for this induction motor is 1.8Ampere. A 1-hp three phase induction motor used for testing the fault conditions treated in this work. The experiment initially was carried out with the speed motor value equal to 1280rpm and the current value equal to 0.55Ampere. At this time, the condition of motor is in normal state. This speed was held for five minutes to enable the machine to reach its stable condition and to generate initial heat in the bearings. In order to create motor bearing fault, which is overload condition; it was imposed on three phase induction motor by increase the input current until exceed the rated current value. By doing so, the current motor value reach until 2.0Ampere. Then, the acquired data is stored in a Personal computer (PC) and analyzed in MATLAB software. The image acquisition processed for normal and abnormal conditions were then conducted.

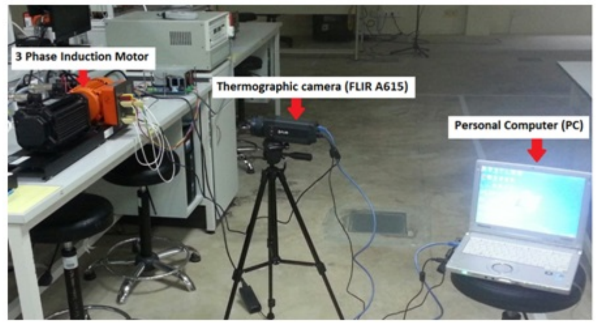

Figure-1. Experimental setup.

Figure-2 below shows a part of three phase induction motor condition that show bearing surface which located at the middle of the coupling between motor and load part. Subsequently, this bearing image is captured using thermal camera and the result image is presented in Figure-3 below. From the naked eye, there is difference color between normal and abnormal bearing image where the color of abnormal bearing image is brighter than normal bearing image. Therefore, these thermal images denote that some pixel value color of abnormal image will gives the higher intensity value than normal image.

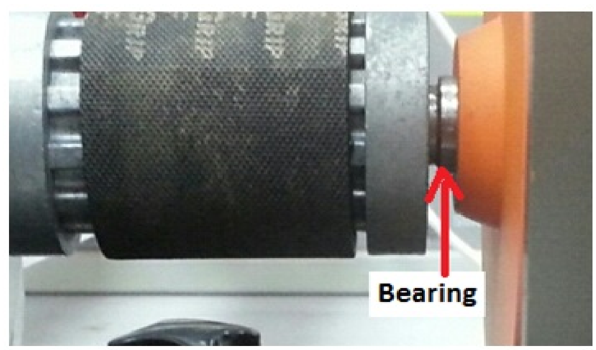

Figure-2. Bearing of three phase induction motor.

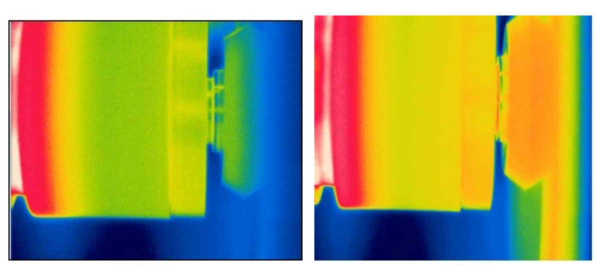

Figure-3. Original thermal image for bearing of 3-phase Induction Motor (a) normal (b) abnormal.

Image segmentation

After the image acquisition process, the image is undergoing the process of image segmentation whereby it will ease to obtain the region of interest (ROI) of the desired output image. Thus, in order to select the ROI of bearing area from the thermal image, Speeded Up Robust features (SURF) algorithm have been employed as an object matching technique to detect desired output automatically between Reference image and Target image of bearing. This SURF algorithm is one of the best feature-based algorithm and is considered as a high-speed, robust and accurate method to extract and describe interest points for any object in an image or a video frame [28]. These features-based make it perfect for object matching and also object detection. Therefore, to characterize the output image bearing motor detection, this SURF algorithm has three main parts to be conducted: (a) Interest point detection, (b) Extract interest point descriptors and (c) Matching.

During image acquisition process, thermal image object, that is, bearing image is cropped first to be used for SURF Reference image. Meanwhile, the original images as illustrated in Figure-3 act as a SURF Target image. At the first stage in object matching, this SURF algorithm has been implemented by "*detectSSURFFeatures*" function to find information SURF features detected in the 2D grayscale Reference image and Target image. Subsequently, extract a number of interest point descriptor from the Reference image and Target image and finally match these points using geometric transformation estimation. Thus, Figure-4 below presents the result of SURF interest matching key points for both Reference image and Target image that will led to the output region of interest of bearing as shown in Figure-5.

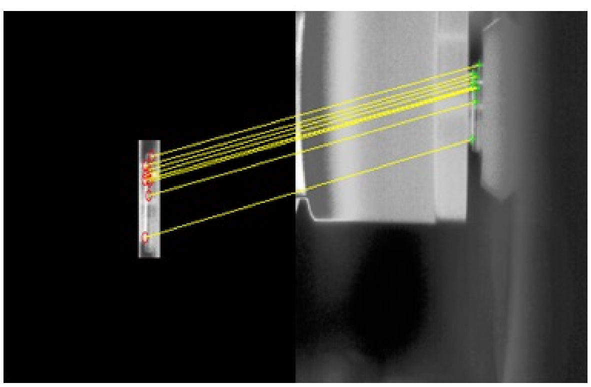

Figure-4. SURF matching points between the reference image (left side) and the target image (right side).

Figure-5. ROI bearing.

When the ROI is segmented, active contour technique is employed in this operation in order to enhance the bearing image to reveal useful features. This active contour model also known as snakes and is implemented in this experiment to detect objects in a given image using techniques of curve evolution. This model is popular in computer vision and greatly used in applications like object tracking, shape recognition, segmentation, edge detection and stereo matching [29].Figure-6 below presents the output foreground described by the binary image.

Figure-6. Enhancing bearing image using active contour segmentation.

Image feature extraction

In image processing architecture, feature extraction is one of the most important stages used for condition monitoring and fault diagnosis, whose aim to make quantitative measurements from the image. All the data pixels that have been grouped which are representing and describe the desired features contain in the image can be extracted for machine condition monitoring and fault diagnosis. Color is one of the most important features of images. A number of color spaces have been used in literature, such as RGB, CIE L*u*v*, CIE L*a*b*, Munsell, YIQ, YUV, YPbPr, YCbCr, YCgCr and YDbDr [30, 31].

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Color features can be extracted from images or regions once the color space has been specified. Thus, in this experiment, RGB color space was implemented due to this approach are straightforward and simple for displaying in monitors. To extract this RGB color information in the image, masking image as depicted in Figure-6 is multiplied first with the original thermal image as indicated in Figure-3. Yields, this multiplication operation will generate a difference intensity color between normal and abnormal thermal image bearing. These values of red, green and blue color can be displayed and represented at each axis of the color cube in the range of [0,255] respectively. 0 means the color component is off (black), while 255 means it's at full intensity and 127 is half intensity. Figure-7 and Figure-8 below indicates image histogram pattern which provide information about the characteristic of the RGB colour distribution under normal and abnormal bearing motor image with x-axis represents the color concentration and y-axis represents the pixel value.

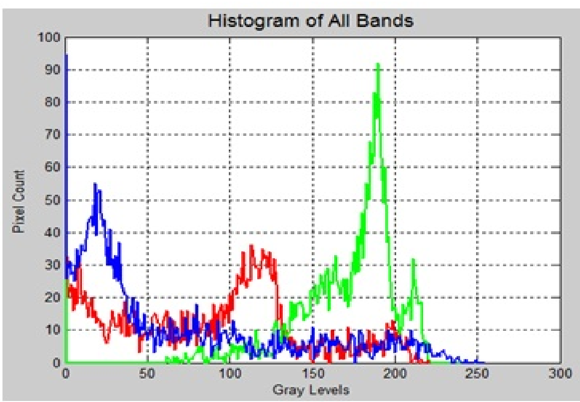

Figure-7. RGB image histogram (normal bearing image)

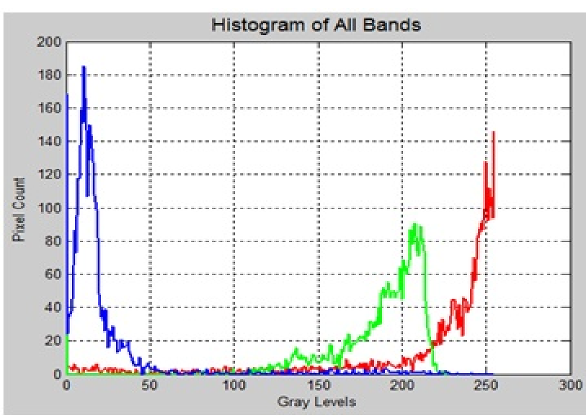

Figure-8. RGB image histogram (abnormal bearing image)

RESULT AND DISCUSSION

Subsequently, histogram features which are truly statistical features which represent image characteristic have been focused in the present study. Generally, this technique is one of the simplest and very effective features techniques to collect and analyze the required data. In this experiment, there are six (6) features that have been extracted from two different machine conditions where each condition has 150 samples. These histogram features consist of mean, standard deviation, skewness, entropy, kurtosis and variance [12, 32]. These features are depicted in Figure-9 until Figure-11 below. All these RGB color features are plotted versus number of samples and then are evaluated to find significant features in order to distinguish the machine conditions.

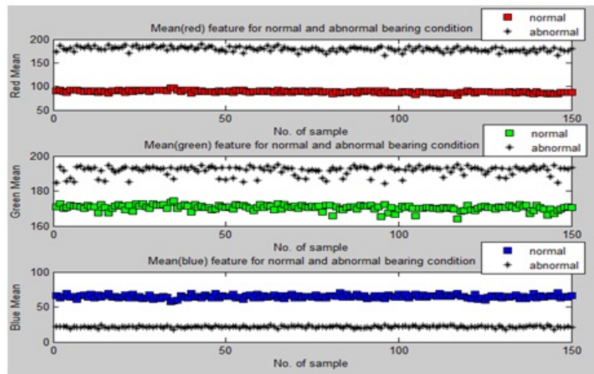

Figure-9. Mean feature of RGB color space.

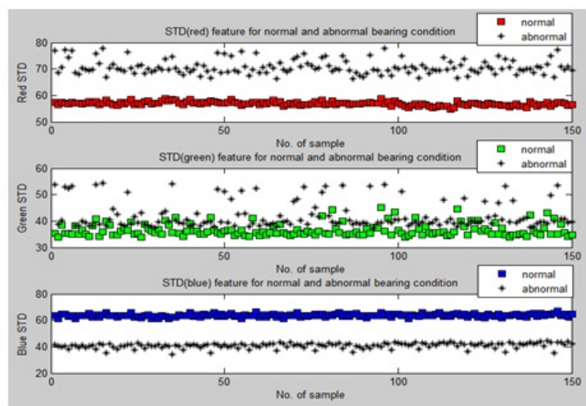

Figure-10. Standard deviation feature of RGB color space.

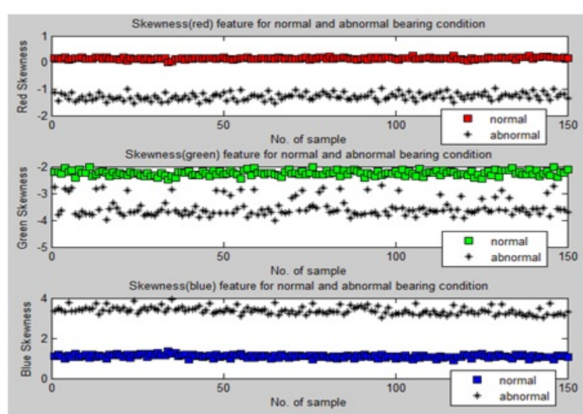

Figure-11. Skewness feature of RGB color space.

VOL. 10, NO. 22, DECEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

The mean, known as average value would give some information about general brightness of the image. Based on Figure-9, it is clearly observed that feature mean for the machine condition is apparently well separated. Figure-9 also indicates the average value feature for normal bearing condition is lower than average value for abnormal bearing condition except for blue (B) color. The average reading for RGB color spaces are shown in Table-1 below where (N) denote to normal condition and (AB) denote to abnormal condition. In RGB color system, the higher the values of R, G and B, the brighter the color will be. Meanwhile, in thermal imaging system, the brighter color in the image represents the hottest temperature area generated by the object. Thus, the higher the values of mean for RGB color space would perceive the brighter the color and represents the hottest temperature area produced by the bearing machinery condition. As a result, the average value for red and green color space has validated the right decision in this experiment. Meanwhile, blue color component perceived lack of contribution in the feature of mean due to the normal machine condition indicated higher reading than abnormal condition machine. Nonetheless, the difference between these two types of motor condition is still able to differentiate clearly.

Table-1. Mean for RGB color space.

Statistic	Red (R)		Green (G)		Blue (B)	
	(N)	(AB)	(N)	(AB)	(N)	(AB)
Mean	89	179	170	192	65	22

Subsequently, the standard deviation, which is also known as the square root of the variance represents dispersion of data away from mean of each data. High brighter color of images will have a high intensity color distribution over image. In mathematical study, to evaluate the standard deviation statistic, the data gained inside the standard deviation area is classified as normal distribution. Meanwhile the data that are outside the range of standard deviation is called abnormal distribution which is the data is too little, too large data or the data are not converging. In the result shown in Figure-10, it was observed that normal bearing condition more converging than the abnormal that were depicted in scattered form. Hereby, by using these standard deviation measurement readings, we capable to classify several of machine conditions thermal images.

Indeed, this standard deviation also is related with the feature of skewness. Normal bearing data in standard deviation would observe normal distribution in feature of skewness. It means, if the skewness data approached to zero, it indicates that the data is in normal distribution condition. Otherwise, it would be abnormal distribution which it means abnormal bearing condition. This skewness for RGB data are proved in Figure-11.

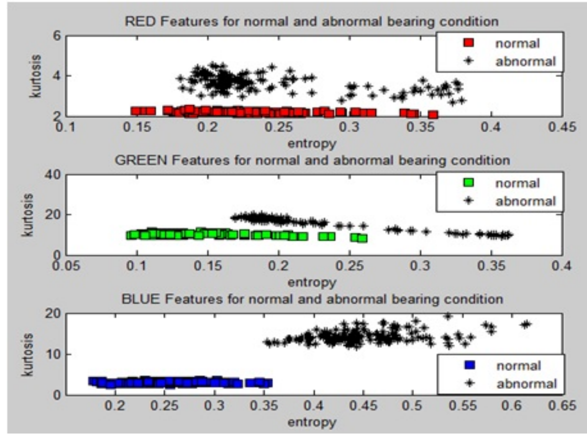

Figure-12. Kurtosis versus entropy of RGB color space.

As can be seen from the Figure-12 above, two features of RGB color spaces are plotted together. There are feature of kurtosis and entropy feature. In mathematical field, kurtosis is a measure of whether the graph input data are in peaked distribution, flat distribution or in normal distribution form. Firstly, in normal distribution form, it will be realized if the output kurtosis value in this distribution is indicated in the zero (0) value. Meanwhile, the output kurtosis value for peak distribution form should be indicated in the positive value and thirdly, flat distribution, the output should be appeared in the negative kurtosis value. In this present study, the graph type of RGB histogram color space as depicted in Figure-7 and Figure-8 are in peak distribution form. Thus, supposedly, the result data kurtosis output in this experiment should be indicated in positive value. Validation has been proved in Figure-12 where kurtosis for RGB color data for both bearing motor conditions have been produced the positive value and those values are presented in table-2 below.

Table-2. Kurtosis for RGB color space.

Statistic	Red (R)		Green (G)		Blue (B)	
	(N)	(AB)	(N)	(AB)	(N)	(AB)
Kurtosis	2.2	3.6	10.2	16.1	3.0	14.3
Entropy	0.22	0.24	0.13	0.22	0.25	0.45

On the other hand, entropy also is indicated in the same Figure-12 with feature of kurtosis. Herein, entropy is a measure that tells us the amount of disorder in a system. In other words, it is the exact state of each molecule formed in the system after transformation from order to disorder. According to Stefan-Boltzman Law, it describes the hotter an object becomes the more infrared energy it emits. It's mean, in this thermal imaging application system, the higher the temperature of the object, the more these atoms and molecules move. As such, as the molecules object increase, the higher the entropy values as well as the higher the temperature value will be produced. This theory has been validated in this experiment where those entropy values are illustrated in Table-2 above. Eventually, in this study, statistical features of RGB color space able to distinguish the differences between these two types of motor condition clearly to be used in diagnosing bearing motor condition.

CONCLUSIONS

In this paper, a thermograph Image extraction based on statistical features on RGB color space for monitoring the normal and abnormal induction motor bearing fault has been proposed. A method called SURF algorithm which is object matching procedure for finding ROIs is introduced. Yet, by adopting active contour segmentation technique, it is employed to enhance the bearing image to reveal useful features. Eventually, six (6) basic features of statistic are presented and have been imposed on the RGB color space. From the result validation analysis, there have been observed that statistical features of RGB color space able to distinguish the differences between normal and abnormal features. Thus, color features vector on RED (R), GREEN (G) and BLUE (B) will be implemented in the next classification stage in order to identify the classification accuracy.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang under the Postgraduate Research Grant Scheme (PGRS) for their financial support

REFERENCES

[1] K. K. Pandey, P.H.Z., S. R. Suralkar. 2012. Review on fault diagnosis in three-phase induction motor. Proceedings published by International Journal of Computer Applications® (IJCA).

[2] Schoen R.R. *et al.* 1995. Motor bearing damage detection using stator current monitoring. Industry Applications, IEEE Transactions on. Vol. 31, No. 6, pp. 1274-1279.

[3] Wei Z., T.G. Habetler and R.G. Harley. 2007. Bearing condition monitoring methods for electric machines: a general review. In diagnostics for electric machines, power electronics and drives. SDEMPED 2007. IEEE International Symposium on.

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

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

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

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

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

[9] Sharmiza Kamaruddin S., Kamarul Hawari Ghazali, Rosyati and Hamid. 2013. Canned pineapple grading using pixel colour extraction. Proceeding of the International Conference on Artificial Intelligence in Computer Science and ICT (AICS 2013) (e-ISBN 978-967-11768-3-2).

[10] Ying-Chieh C. and Y. Leehter. 2009. Automatic diagnostic system of electrical equipment using infrared thermography. In soft computing and pattern recognition. SOCPAR '09. International Conference.

[11] Achmad Widodo D.S., Toni Prahasto Gang-Min Lim,Byeong-Keun Choi.2012. Confirmation of thermal images and vibration signals for intelligent machine fault diagnostics. International Journal of Rotating Machinery.

[12] Ali Md. Younus, A.W., Bo-Suk Yang. 2009. Application of thermal image: machine fault diagnosis using PCA and ICA combine with SVM.

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

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

[15] Tran V.T. *et al.* 2013. 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. Vol. 38, No. 2, pp. 601-614.

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

[17] Younus A.M.D. and B.-S. Yang.2012. Intelligent fault diagnosis of rotating machinery using infrared thermal

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

image. Expert Systems with Applications. Vol. 39, No. 2, pp. 2082-2091.

[18] Asiegbu G., Haidar A. M. and Hawari K.2012. Non-destructive defect detection on electrical equipment using thermographic technology. International Review on Computers and Software. Vol. 7, No. 3, pp. 919-927.

[19] Ghazali K.H.H., R. S. Zeehaida M.January 2014. Comparison of image pre-processing approach for classification of intestinal parasite ascaris lumbricoides ova and trichuris trichiura ova. Advanced Science Letters. Vol. 20, No. 1, pp. 116-119(4).

[20] Kamarul H. Ghazali, R.S.H.A., Zeehaida Mohamed.2013. Automated System for Diagnosis Intestinal Parasites by Computerized Image Analysis. Modern Applied Science. Vol. 7, No. 5.

[21] Kamarul Hawari Bin Ghazali, J.M., Rui Xiao.October 2011. Multi-angle face detection using back propagation neural network. Journal of Applied Mechanics and Materials. Vol. 121 – 126, pp. 2411-2415.

[22] Kamarul Hawari Ghazali, J.M., Rui Xiao,October 2011. An innovative face detection based on skin color segmentation. International journal of computer application. Vol. 34 – No. 2, pp. 6-10.

[23] Kamarul Hawari Ghazali, M.M.M., Aini Hussain.2008. Machine vision system for automatic weeding strategy using image processing technique. American-Eurasian Journal of Agricultural & Environmental Science. Vol. 3, pp. 451-458.

[24] Kamarul Hawari Ghazali, M.M.M., Aini Hussain, Saifudin Razali.2008. Scale invariant feature transform technique for weed classification in oil palm plantation. Journal of applied sciences. Vol. 8, No. 7, pp. 1179-1187.

[25] Kamarul Hawari Ghazali, M.M.M., Aini Hussain, Saifudin Razali. 2008. Weed classification for automatic weeding strategy: a comparison of two image processing techniques. International Journal of Soft Computing Applications, No. 2, pp. 62-68.

[26] Sharmiza Kamaruddin, S., Kamarul Hawari.2013. Canned pineapple grading using colour analysis. International Journal on Latest Trends in Electronics and Electrical Engineering (IISRO Journal). Vol. 1, No. 1, pp. 118-122.

[27] Ahmed M. A. Haidar, K.H.a.F.A.F.I.January. 2012. Electrical defect detection in thermal image. Advanced Materials Research. Vol. 433-440 pp. 3366-3370.

[28] Bay H. *et al.* 2008. Speeded-up robust features (SURF). Computer Vision and Image Understanding. Vol. 110, No. 3, p.p 346-359.

[29] Blake A. and M. Isard.2012. Active contours: the application of techniques from graphics, vision, control theory and statistics to visual tracking of shapes in motion. Springer Science & Business Media.

[30] Chaves-Gonz J.M. *et al.* 2010. Detecting skin in face recognition systems: A colour spaces study. Digit. Signal Process. Vol. 20, No. 3, pp. 806-823.

[31] Plataniotis, K.N. and A.N. Venetsanopoulos. 2000. Color image processing and applications. Springer-Verlag New York, Inc. 355.

[32] Lakhmi C. Jain, H.S.B., Jyotsna Kumar Mandal, Durga Prasad Mohapatra.2014. Computational Intelligence in Data Mining – Vol. 3. Smart Innovation, Systems and Technologies. 33.