FAULT DIAGNOSIS IN ELECTRONICS EQUIPMENT USING THERMAL IMAGING: A REVIEW

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Abstract: Electronics circuit boards have a significant potential in all the application over the world, so there is need to diagnose the faults and failure at early stage in on board electronics equipment to reduces the downtime of equipment or increase the machine availability of the system or equipment. Moreover, it is critical to improve accurate and remote fault detection techniques for these electronics equipment. This paper has comprehensively summarized and highlighted the couple of faults in electronics equipment's and their diagnostic technique using thermal imaging (TI). Additionally, the problems and potential developments in fault diagnosis for the electronics system based on thermal imaging are addressed and analyzed. Finally, based on TI, this paper will act as a reference for flaw identification and fault diagnosis of on board electronics equipment.

Index Terms **- Thermal imaging (TI), Electronics equipment, Fault Diagnosis, Condition Monitoring.**

I. INTRODUCTION

As technology has slowed, the density of Very Large Scale Integrated (VLSI) chips has increased exponentially. As a consequence, quick cycle times and automated processes are needed for mass VLSI processing. As a result, there have been a slew of reliability problems, such as defects in chip fabrication. Thermal testing has increased in popularity as a non-destructive testing method in recent years, owing to the fact that infrared (IR) technology is now a very viable method for non-contact PCB testing. Thermal imaging testing is also a fast, safe, and The equipment used in such applications is secure [1,2]. Experiments on thermal imaging of Printed Circuit Boards (PCBs) using various thermal imaging techniques were also included in several processes. Thermal testing of printed circuit boards (PCBs) is conducted in [3], and the proposed approach is used to categorize Integrated Circuits (ICs) into three major categories (e.g. faulty, functional fault free and non-functional). To classify the samples extracted from the IR image, the classification method employs an artificial neural network. The only disadvantage of this method is the time and expense of obtaining the thermal signature for each test vector added to the PCB's primary inputs. [4] suggested a method for thermal analysis of the PCB using MATLAB. Based on the loading state of the PCB, two criteria are used for thermal image analysis: the highest temperature and the maximum region of the highest temperature. However, this analysis is not recommended for complex PCBs because clustering based on segmentation methods should enhance the option of selecting a region of interest. [5,] conducted a qualitative measurement of thermal anomalies by detecting the feature point and area of concern with the stable zone algorithm and comparing it to Euclidian scale. [6] describes how thermal image processing can be used to detect defective regions on a PCB. TI has a variety of applications such as electrical motor [7-11] and mechanical maintenance [12], agriculture [13], aviation, geological survey [14], automotive [15], medical [16]. Non-destructive testing (NDT) methods are currently being studied briefly in [17-21]. However, an analysis study is also needed, including the IRT techniques for main RSE system equipment in the last five years, the benefits and weaknesses of these IRT techniques, and possible research patterns. Furthermore, the majority of recent works have focused on the implementation of IRT theory. IRT image recognition and fault diagnosis algorithms in core equipment contribute significantly to academic and industrial science. Nonetheless, all pertinent material is spread throughout various pieces of literature, which are seldom reviewed. This article has a thorough summary and illustrates cutting-edge approaches for IRT techniques in core RSE device equipment. IRT strategies' challenges and future developments are also addressed. The RSE energy management strategy is used to assess the implementations of IRT technologies in concentrated solar receiver (PTR) [22] and energy storage (Mppt) cell [23]. This paper focuses on the use of IRT technologies in the RSE transmitting and new platforms in insulated gate bipolar transistors (IGBTs) [24] and insulators [25]. The RSE storage system explores the uses of IRT techniques in electrochemical sensors (PEMFC) [26] and battery packs (LIB) [27].

Some authors also focused on temperature analysis of PCBs using various thermal imaging techniques. Thermal analysis on PCB is performed using the Galerkin method, and a FEM model is used to study and measure temperature increase on PCB with varying copper widths and current amounts [28]. Another research on thermal stability of components on PCB is conducted using ANSYS tools to boost device reliability [29]. The thermal irregularities are then measured qualitatively by identifying feature points and regions of interest with MSER and comparing THEM WITH EUCLIDIAN DISTANCE [30]. The feature point algorithm [31] is used to diagnose faults in component positions on PCBs. Vector quantization is used in the analysis of PCBs for fault diagnosis, and the data is fed into a neural network [32]. The same research is carried out with a support vector claSSIFIER AND A NEURAL NETWORK [33]. Peak temperature, mean temperature, maximum temperature gradient, and temperature differential metrics are some of the most often employed thermal functions. We use the statistical analysis tool Principal Component Analysis to speed up the processing of infrared image sequences produced by various heating techniques. The most often used thermal properties are peak temperature, mean temperature, maximum temperature gradient, and temperature differential measures. We use the statistical analysis tool Principal Component Analysis to speed up the processing of infrared image sequences produced by different heating techniques. In this case, PCA is used for data compression and improved pattern matching. Principal Component Thermography refers to the application of principal component analysis (PCA) to thermographic image data (PCT). To minimize the amount of computation needed, the real PCT, the SVD computing technique is used. The thermal image's attribute extraction is obtained from the engineered device setup and fed into the Euclidian distance for fault detection and recognition.

II. BACKGROUND OF THERMAL IMAGING

Sir William Herschel discovered the initial value of the infrared spectrum in the year 1800 while looking for a new optical material. He started his work with a lamp made of a mercury-in-glass thermometer. He went on to research the heating effect of the various colors of the spectrum by passing sunlight through a glass prism, where he discovered that the temperature measurements display a constant increment from violet to red. Langley created a bolometer in 1880 that increased the efficiency of infrared detection. It allowed the quantification of the intensity of solar radiation at different wavelengths. To determine the thermal radiation produced by the engine, we must first determine the reflected light. Reflected temperature must be measured in order to quantify reflected radiation, which is then considered to be the same for all reflecting surfaces. Using Kirchhoff's theorem, it is presumed that the emissivity of the surrounding medium is equal to one.

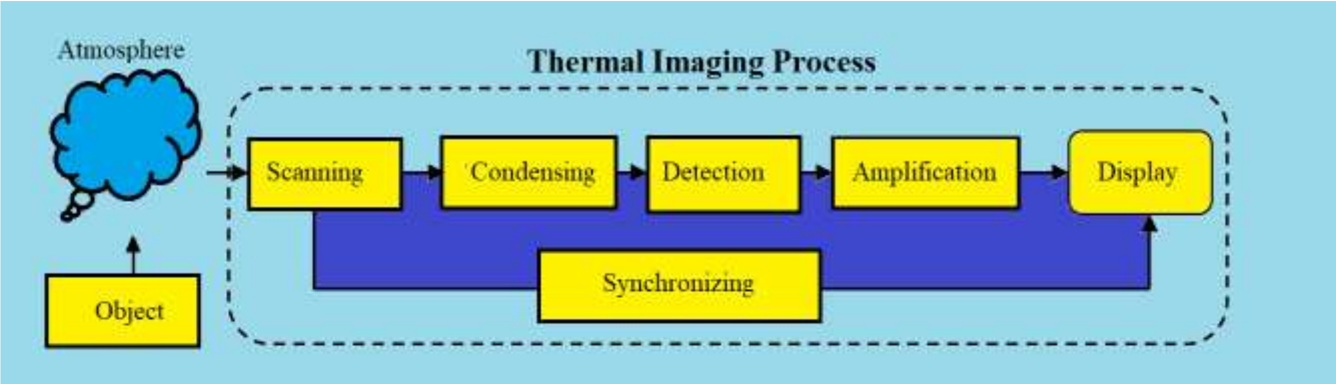

Fig. 1 Block Diagram of thermal imaging process

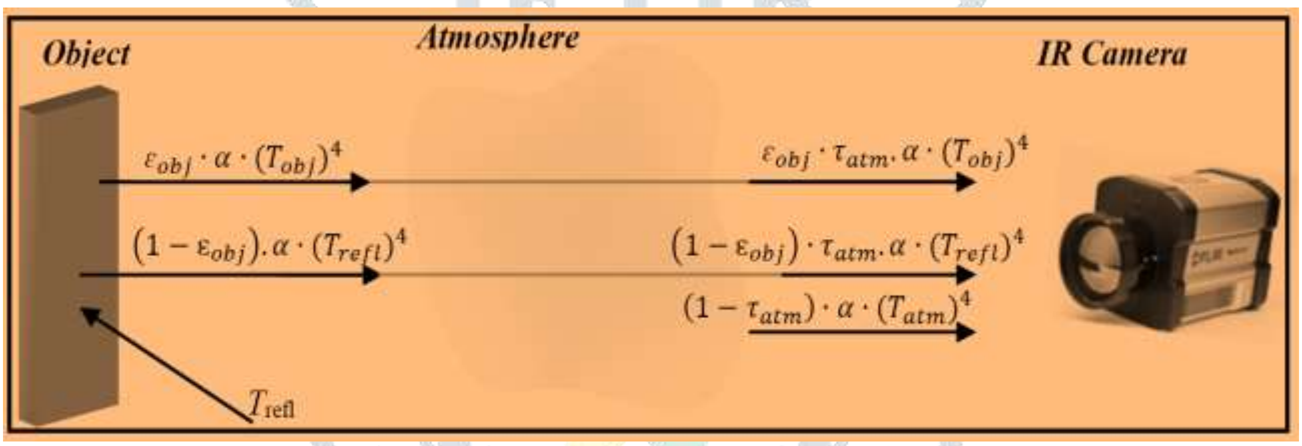

Fig.2 Radiation absorbing process by the thermal imaging devices

The camera includes the IR optics, IR sensor, unit for conversion of electrical into video signals, display, and memory card. Thermography processing unit is processor unit or a Personal Computer (PC) using special software, and they process data from the camera memory card. A main block diagram of measurement by infrared thermography equipment is shown in figure 3.1 [23]. Thermal testing, also known as infrared thermography testing, is used to determine surface temperatures using infrared radiation released by an object's surface as liquid. Thermal instruments, such as an infrared camera, can detect infrared radiation. The thermal image captured can be studied to collect knowledge about both the device subsurface radiant body, which could then be used to comprehend its situations. This knowledge is useful in identifying the presence and type of abnormalities in the body. Thermal imaging has become a stand-alone technique for evaluating a range of applications in recent years, due to advances in infrared cameras and data processing codes [20]. The fundamental of faults, defects, and failure relationship was reviewed in this chapter. The main kinds of faults occurring in VLSI chips were described. The benefit of working with the simulation process for fault detection in the VLSI circuits was defined. The difference between destructive and non-destructive testing methods for PCB was presented. Importance of using infrared thermography for VLSI circuit testing was illustrated.

III. TYPE OF DEFECTS IN ELECTRONICS PCBS

The defect is defined as the difference between the aimed design and the implemented hardware. If any component fails to do its duties, its output will be drastically changed. In this case, a component is said to have a fault. Fault is a representation of a physical defect reflecting a physical condition that causes a circuit to fail to do in a required way. A failure is defined as the inability of the component to perform its design role. A failure in a system is due to the incorrect design and specifications, defects during the manufacturing process, or due to the aging and environmental causes. In the past, the main sources of defects in VLSI circuits were opened, shorts and bridges circuits. This is expected to stay in complex circuits where the increasing number of PCB layers leads to a risk of open vias and metal bridges. Nowadays, in silicon technologies, shorts and open due to the particles and spots, opens in vias and interconnection lines, solicitation problems, etc. are commonly seen. In addition, in this context, new technologies introduce new types of defects which we explain about them. These types of faults occurring in VLSI circuits can be arranged as follow:

a) **Resistive Bridge Defects:** these defects happen when two or more distinct nodes of the circuit get connected due to a fault. Resistive bridge defects are one of the typical commonly of manufacturing defects. Figure 2.1.a, shows a bridge defect between two parallel interconnection lines [12].

b) **Resistive opens defects:** defined as an imperfect resistor connected between two circuit nodes. A pinned defect is really a subset of a resistive open with an increased resistance value. These include open contacts, metallization open and open in diffusion [13, 14].

c) **Interconnect malfunctions:** a full open in an interconnection happens when the conductive material is fully broken. The main causes for the interconnecting open defects during the manufacturing process can be due to the several factors, such as chemical polishing process, metal filling, spots during the lithography, and lens imperfections. This defect is an interconnected line, shown in figure 2.1.b [12].

d) **Delay defect:** These faults allow a circuit's cumulative delay to surpass the clock time. Delay fault includes gate-delay fault, line-delay fault, and path-delay fault.

e) **Memory defects:** faults happened in memory sections are normally pattern sensitive, cell coupling, and single stuck-at faults in the address decoder logics.

f) **Parametric defects:** They refer to the difference between the actual and expected power or performance criteria for the component. For example, IC may function at a certain voltage, but not over the designed range.

g) **Temperature-dependent defects:** They arise where a link between the two circuit nodes has a conductivity of the material that is either too high or too low to be linked at average temperatures. This defect is environmentally sensitive, and appears only under certain environmental conditions. However, or at high temperatures and low, the conductance falls so low that the bond is severed. [15].

h) **Early-life Failures:** Some individual ICs will fail early. These failures is as production faults that are not exhibiting as a faults shortly after producing. Defects and mistakes always cause early-life failures: material defects, design mistakes, errors in assembly, etc. This type cannot be detected by the manufacturing test that is performed at once after the fabrication process [15].

IV. Fault Diagnosis Techniques

Detection and locating of faults in a digital circuit or PCB, is known as the fault diagnosis. With VLSI technology scaling, fault diagnoses techniques are important to replace or discard the faulty component in the board. Furthermore, fault testing is the method of modelling a circuit using a series of test conditions and defects. The response of the circuit compares with the fault-free circuit. If the response does not match, the set of test patterns detects the fault [16].

a) Digital PCB Testing Methods

The aim of testing methods is the successful scanning of engineered circuits in order to find flaults. Because of this work deals with thermography-related VLSI test methods, focus on test of PCBs that are VLSI techniques [15]. Based on the variety of models on different levels of abstraction, several destructive and non-destructive test methods have been developed to perform the efficient and highly reliable testing procedures that detect the internal features or surface of the PCB components [17, 18].

b) Destructive Testing Methods

There are many conventional destructive testing techniques proposed so far that can check the VLSI circuits with some techniques such as logic, functional, delay and/or current testing such as scan path design, Level Sensitive Scan Design (LSSD), scan logic, random access scan, built –In –Self Test (BIST) technique, the ad-hoc technique, partitioning technique, adding extra pin's techniques, and signature analysis technique. However, with developing the PCB production technologies; these destructive testing methods are restricted obviously. At the moment, PCBs are getting denser and have more electrical nodes. This PCBs would stop getting too many reference points, which restricts the output measurement process to just testing the electrical nodes. Contact PCBs and potentially damaged PCBs are needed for the electrical performance testing process. Since this approach necessitates a fixture for each PCB, the cost is large.

c) Non-destructive Testing Methods

With Non-Destructive Testing (NDT) methods, we can detect, locate, measure, and test surface or internal layers of the components causing no damage or change the integrity of its properties. Thus, non-destructive testing can be done efficiently for the manufactured items. Today, modern nondestructive tests are used in production fields to ensure product functionality and reliability. Several types of the NDT procedures are being used in the industry such; Acoustic Emission Testing (AET), Thermal or Infrared (IR) Testing, Ultrasonic Testing (UT), and Radiographic Testing (RT). Each of these techniques has its own advantages and disadvantages that mainly relate to the testing system cost, speed, accuracy, and safety. Following sections present the most often used NDT methods such as UT, RT, AE, and IR [20].

d) Ultrasonic Testing method

Ultra-high frequency wave is sent into the component to detect an internal structure of an element under the test. The main advantage of the ultrasonic testing technique is that it can seep into objects of high thicknesses and, therefore, the flaws can be distinguishable. The main disadvantage of it is that it requires the materials which should be homogenous with uniform surface roughness. It requires a medium to transmit the waves from the transducer into the bulk, additionally, and ultrasound is a point inspection technique that can be time-consuming for large areas.

e) Radiography Testing

In radiography, the sample shadow is generated using penetrating radiation rays, such as gamma or x-ray. Images are recorded using x-rays on the film called as radiograms. The recorded radiograms have different contrast levels depending on the flaws, thickness, densities, and the nature of its chemical composition. Radiograms require access from both sides of the sample being tested because it operates based on a transmission mode.

f) Acoustic Emission Testing

Acoustic emission is the phenomenon of sound generation in materials when they are under stress. Many materials designed to withstand high levels of stress emit acoustic energy when stressed. Acoustic emission is used to track structural integrity and characterize material movement when it deforms, cracks, or both. Unlike ultrasonic or radiography techniques, acoustic leakage does not necessitate the use of additional energy for inspection. Acoustic emission methods have been used to inspect components and equipment as they are handled, as well as to detect and spot leaks and test pressurized vessels. One of the most important problems with acoustic pollution is the massive amount of evidence that must be preserved and retrieved for research purposes.

g) Thermal Imaging Testing

Thermal testing, or infrared thermography testing, is used to measure the surface temperatures based on the infrared radiation which is emitted from the surface of an object as heat. The infrared radiation can be detected using thermal devices such as the infrared camera. The thermal image captured can be analysed to obtain information about the component subsurface thermal body, which can then be used to understand its internal configuration. This awareness can be used to diagnose the occurrence and form of anomalies in the body. Due to advancements in infrared technology, thermal imaging has become a stand-alone tool for analyzing a wide variety of applications in recent years. Due to advancements in infrared cameras and data processing codes, thermal imaging has become a stand-alone tool for testing a wide variety of applications in recent years [20]. The fundamental of faults, defects, and failure relationship was reviewed in this chapter. The main kinds of faults occurring in VLSI chips were described. The benefit of working with the simulation process for fault detection in the VLSI circuits was defined. The difference between destructive and non-destructive testing methods for PCB was presented. Importance of using infrared thermography for VLSI circuit testing was illustrated.

V. Thermal Imaging Techniques as Diagnosis Tool

Thermal imaging is widely used and has received particular interest from the NDT&E community due to its unique properties, which include non-destructive, non-invasive, non-contact, simple, and detailed area inspection. Using a thermal camera, IRT measures the spread of heat radiation over the sample surface and tracks the temperature change over time. IRT has a diverse set of uses. ANSYS software is used to enhance the reliability of thermal behavior analysis based on thermal images of circuits boards. Furthermore, thermal images were captured and extract the region of interest using segmentation and finally, comparative analysis was done between adaptive neuron-fuzzy inference systems (ANFIS) and support vector machine (SVM) [7]. Temperature is the most common parameter used as a parametric test detectable for ICs in various contexts, while thermal imaging is a temperature measuring procedure that measures invisible infrared radiation and transforms the energy from visible light into an electrical signal. The thermal imaging technique seems to be completely non-contact. Since images of components are difficult to physically access, thermal technique can scan them. Thermal testing methods can be defined as temperature measuring for the PCB fault detection. In certain ways, non-contact thermal diagnostics is struggling with the traditional approach diagnose the PCB circuits. Thermal imaging for defect detection in PCB circuits is more efficient than the standard approach, which involves checking several nodes before finding the node with the variance characteristics. Also after finding the defective node, it is important to examine the several of its related components in order to pinpoint the exact faulty parts. Thermal imaging is often more efficient in identifying concealed defects in electronic circuits, as long as the appearance of those defects does not affect the electrical properties of the circuit but does result in a malfunction for some time.

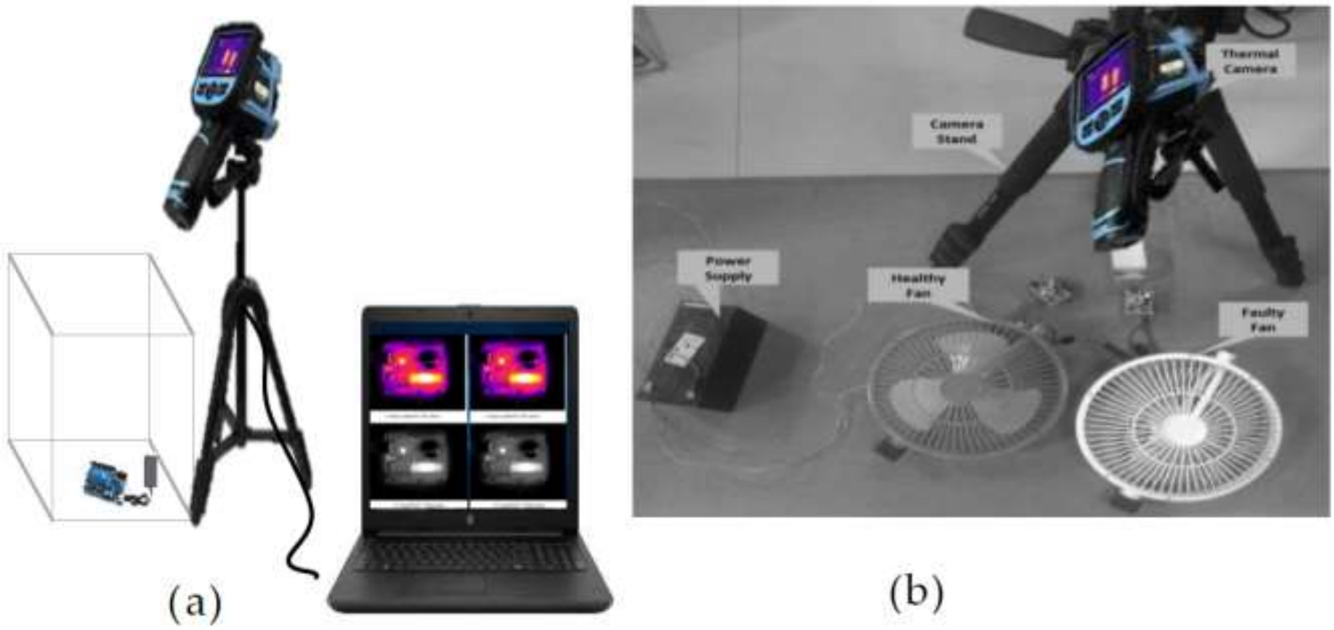

Fig. 3 The experimental setup of thermal imaging techniques

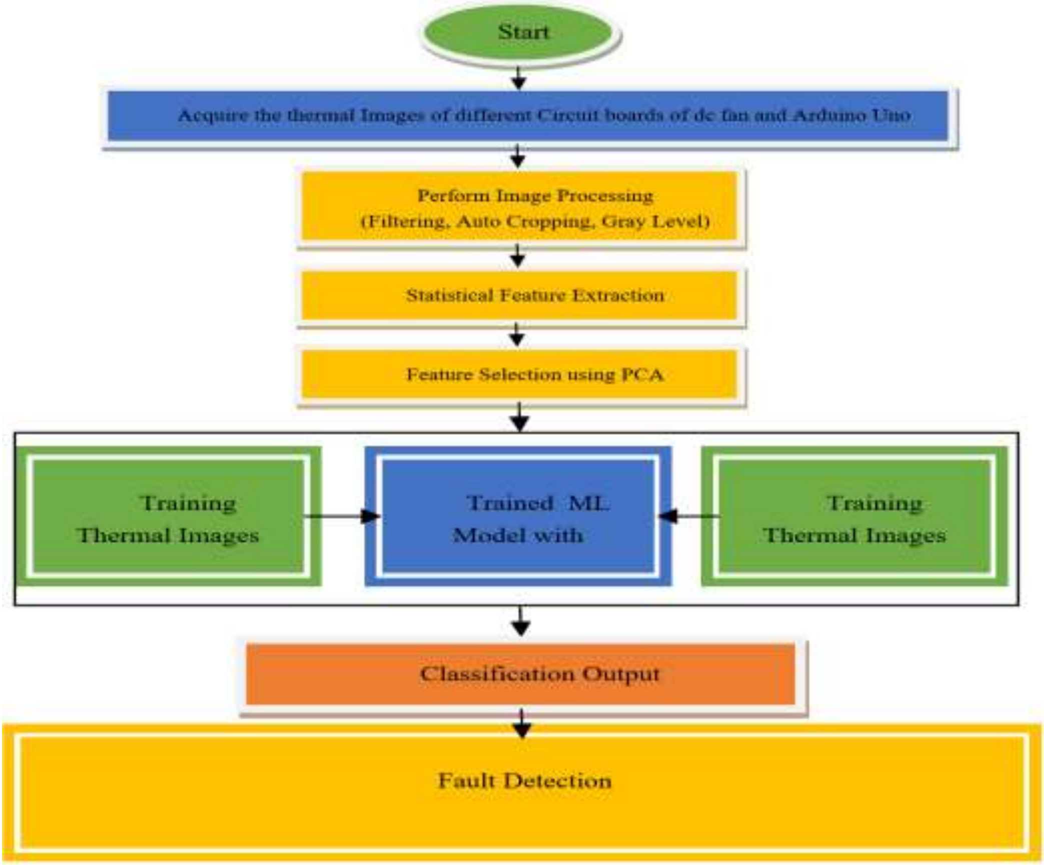

Fig.4 The basic flow diagram of thermal imaging based fault diagnosis in Electronics component

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VI. **RESULTS AND DISCUSSION**

Although several techniques in the literature were proposed to study fault detections and diagnosis, still challenges related to the performing reliable testing systems for PCB manufacturing has been remained because of increasing complexity of PCBs. The goal of this thesis is to develop an intelligent testing approach to tackle these related challenges. The aim of our work is to develop a more robust method at each processing stage to improve the condition for fault detection in the UUTs. Main contributions of our work are as follows:

- ✓ Infrared thermography as a non-destructive fault detection testing of PCB is presented. The fundamental and essential theoretical background in this field have been reviewed in this thesis. This background information is provided to help and assist the researchers of these technologies in a better understanding of the subject.

- ✓ In this thesis, a three-dimensional PCB model comprising five physical layers has been designed and simulated by the FE analysis software. The IR images for the PCB model are captured and successfully presented.
- ✓ Through a preprocessing step, to remove the thermal noise (i.e. Salt & pepper + Gaussian noises) from IR images, combination of Median and BM3D filters is applied. Performance of this advanced filter is verified by using the performance metrics such as SNR and PSNR factors.
- ✓ The enhanced IR images are segmented and cropped to identify ROI object. Various algorithms have compared the IR image to a threshold. From the results, it can be inferred that the Otsu's algorithm works better for IR images as compared with the other thresholding algorithms. The Otsu's algorithm works on finding the best optimum threshold value and minimizing the variance among the different image pixels.
- ✓ After that, the PCA is performed on the first and second order of histogram features to extract the major information, which reduces the number of features significantly. These major features are then fed into the intelligent classifier models for training and then testing.

VII. CONCLUSION

Infrared thermography has emerged as an important state control technique for non-contact real-time temperature monitoring of artefacts or systems. This research paper primarily conducted an orderly, succinct literature survey as well as a detailed and in-depth summary of the uses of IRT inspection technologies in NDT and fault detection for key electronics device equipment over the last five years. It offers vital knowledge about the health and reliability of facilities or systems, which is critical in avoiding catastrophic loss or emergency shutdown. The use of digital image processing techniques on obtained infrared thermal photographs, in conjunction with artificial intelligence-based methods, will further augment the decision-making process, making it quicker and with less human intervention. This review will also enable non-specialists in industries to use this methodology for different condition management applications, minimizing downtime, repair costs, and the likelihood of injuries while increasing efficiency and development.

REFERENCES

[1]. Philemon Daniel P . Software-based self-test techniques for online test and diagnosis of embedded controllers and memories. Hamirpur, India: Dept. Electro. Comm. Eng. Nat. Inst. of Tech.; 2014.

[2]. Yabin Z , Bagnoli PE . A modeling methodology for thermal analysis of the PCB structure. Microelectr J. 2014;45(8):1033–52.

[3]. Moldovan H , Marco M , Vladutiu M . PCB testing using infrared thermal signature. In: Proc. IEEE int. conf. instrum. meas., vol. 3; 2005. p. 1970–4.

[4]. Varghese k J , Singh T , Mohan S . PCB thermal image analysis using MATLAB. Int J Adv Eng Tech 2014;2(3):46–52.

[5]. Taib S , Jadin M , Kabir S . Thermal imaging for qualitative-based measurements of thermal anomalies in electrical components. In: Proc. IEEE int. conf. electron. commun; 2011. p. 1–6.

[6]. Wagh CR , Baru VB . Detection of faulty region on printed circuit board with IR thermography. Int J Scientific Eng Res 2013;4(11):1–4.

[7]. Choudhary, A., Goyal, D., & Letha, S. S. (2020). Infrared Thermography-Based Fault Diagnosis of Induction Motor Bearings Using Machine Learning. IEEE Sensors Journal, 21(2), 1727-1734.

[8]. Choudhary, A., Shimi, S. L., & Akula, A. (2018, September). Bearing fault diagnosis of induction motor using thermal imaging. In 2018 International Conference on Computing, Power and Communication Technologies (GUCON) (pp. 950-955). IEEE.

[9]. Mehta, A., Choudhary, A., Goyal, D., & Pabla, B. S. (1800). Infrared Thermography Based Fault Diagnosis and Prognosis for Rotating Machines.

[10]. Choudhary, A., Goyal, D., Shimi, S. L., & Akula, A. (2019). Condition monitoring and fault diagnosis of induction motors: A review. Archives of Computational Methods in Engineering, 26(4), 1221-1238.

[11]. Sharma, A., Verma, P., Choudhary, A., Mathew, L., & Chatterji, S. (2021). Application of Wavelet Analysis in Condition Monitoring of Induction Motors. In Advances in Electromechanical Technologies (pp. 795-807). Springer, Singapore.

[12]. Maldague X ,"Theory and Practice of Infrared Technology for Non Destructive Testing" in John-Wiley & Sons, New Jersey,ISBN: 978-0- 471-18190-3, USA 2001.

[13]. R. Ishimwe, K. Abutaleb, and F. Ahmed, "Applications of thermal imaging in agriculture a review," Advances in Remote Sensing, vol. 3, no. 03, p. 128, 2014.

[14]. J. Rinker, “Airborne infrared thermal detection of caves and crevasses,” Photogrammetric engineering and remote sensing, vol. 44, no. 11, 1975.
[15]. M.-H. Wang, P.-C. Wu, and W.-J. Jiang, “Application of infrared thermography and extension recognize method to intelligent fault diagnosis of distribution panels,” IEEJ Transactions on Electrical and Electronic Engineering, vol. 10, no. 4, pp. 479–486, 2015.
[16]. E. Ring and K. Ammer, “Infrared thermal imaging in medicine,” Physiological measurement, vol. 33, no. 3, p. R33, 2012.
[17]. H.F. Zhou, H.Y. Dou, L.Z. Qin, Y. Chen, Y.Q. Ni, J.M. Ko, et al., A review of fullscale structural testing of wind turbine blades, Renew. Sustain. Energy Rev. 33 (2014) 177–187.
[18]. P. Hacke, S. Lokanath, P. Williams, A. Vasan, P. Sochor, G.S. Tamizhmani, et al., A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols, Renew. Sustain. Energy Rev. 82 (2018) 1097–1112.
[19]. R. Gade, T.B. Moeslund, Thermal cameras and applications: a survey, Mach. Vis. Appl. 25 (2014) 245–262.
[20]. S. Bagavathiappan, B.B. Lahiri, T. Saravanan, et al., Infrared thermography for condition monitoring- a review, Infrared Phys. Technol. 60 (2013) 35–55.
[21]. R. Alfredo Osornio-Rios, J. Alfonso Antonino-Daviu, R.T. Rene, Recent industrial applications of infrared thermography: a review, IEEE Trans. Ind. Inf. 15 (2) (2019) 615–625.
[22]. J. Liu, D. Lei, Q. Li, Vacuum lifetime and residual gas analysis of parabolic trough receiver, Renew. Energy 86 (2016) 949–954.
[23]. G. Balasubramani, V. Thangavelu, M. Chinnusamy, et al., Infrared thermography based defects testing of solar photovoltaic panel with fuzzy rule-based evaluation, Energies 13 (2020).
[24]. K. Li, G.Y. Tian, L. Cheng, A. Yin, W. Cao, S. Crichton, State detection of bond wires in IGBT modules using eddy current pulsed thermography, IEEE Trans. Power Electron. 29 (2014) 5000–5009.
[25]. Z. Zhao, X. Fan, G. Xu, L. Zhang, Y. Qi, K. Zhang, et al., Aggregating deep convolutional feature maps for insulator detection in infrared images, IEEE Access 5 (2017) 21831–21839.
[26]. G. Bender, W. Felt, M. Ulsh, Detecting and localizing failure points in proton exchange membrane fuel cells using IR thermography, J. Power Sources 253 (2014) 224–229.
[27]. M.A. Hannan, M.S.H. Lipu, A. Hussain, A. Mohamed, A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: challenges and recommendations, Renew. Sustain. Energy Rev. 78 (2017) 834–854.
[28]. Mohd Norhisham Che Soh, “Thermal Analysis on PCB us-ing Galerkin Approach”, IEEE, 2011.
[29]. Shaoting Xu, Xunbo Li, “Analysis on Thermal Reliability of Key Electronics Components on PCB Board”, IEEE, 2011.
[30]. Mohd Shawal Jadin, Shahid Kabir, “Thermal Imaging for Qualitative-based Measurements of Thermal Anomalies in Electrical Components”, IEEE, 2011.
[31]. Jun Xu, Jianliang Li, Y. Jiang, “Components Locating in PCB Fault Diagnosis Based on Infrared Thermal Imaging”, IEEE Conference on Information and Computing Science, 2009.
[32]. S. Huang, Chi-Wu Mao and K. Cheng, “A VQ-Based Ap-proach to Thermal Image Analysis for Printed Circuit Boards Diagnosis” IEEE Trans.on instumentation and measurment, VOL. 54, NO. 6, DEC. 2005.
[33]. Wan Jiuquing, Li Xingshan, “PCB Infrared Thermal Imag-ing Diagnosis using Support Vector Classifier”, 4th World Congress on Intelligent Control and Automation, IEEE, 2001.