



PCB Thermal Image Analysis using MATLAB

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Abstract— This paper explains a method for Printed Circuit Board (PCB) thermal image analysis using MATLAB. In this method, a train of thermal images of the PCB in chronological order are used as input. Each image corresponds to a maneuver or a particular loading condition of the PCB. The two parameters used for analysis are peak temperature and maximum area of the peak temperature which co-relate with the heat dissipation regions. This program provides a MATLAB based Graphical User Interface (GUI) for the design engineer to select the most critical image from the lot, see the temperature jump (in the form of difference image) and view the series of images in the form of a video for quick analysis.

Index Terms— PCB, Thermal Image, Thermal Analysis.

I. INTRODUCTION

Thermal analysis of an electrical / electronic system is an essential part of the circuit design process. The heavy duty electrical parts need to be designed taking the thermal loading into account. This is all the more important for the Electronic Control Units (ECUs) which work in severe environmental conditions like automotive engine, brake or transmission control units.

During thermal analysis, the ECUs are electrically loaded to the extreme in a thermal chamber which is set at the test ambient temperature. Thermal images are taken using an Infra Red (IR) camera at different loading instants. These images are then analyzed manually to get the hotspots and heat spread. These inputs are used to do the proper thermal design e.g select appropriate heat-sink, design the required thermal conductivity via, copper inlay and re-routing the high power traces on the PCB.

Sometimes the test continues for extended duration like overnight, and the camera is programmed to take images at regular intervals throughout the test duration. Often the number of images is in hundreds or even in thousands. It becomes very difficult and time consuming to do a comparative analysis of so many images. This paper explains a MATLAB based tool to analyze all these images and draw useful conclusion precisely in much lesser time.

Electronic component density on current PCB designs is higher than ever, and with the corresponding increase in power density, it's difficult for a PCB designer to ignore thermal effects. The impetus for doing PCB thermal analysis is the simple fact that electronic component power is derated based on temperature. The higher the temperature, the lower the electrical performance. Thermal analysis assists the designer in determining the electrical performance of the components on the PCB and it also helps the designer determine if the component or PCB will burn up due to high temperatures. Thermal analysis can be as simple as the calculation of the average temperature of a PCB, or it can be as complicated as a transient model of an electronics box with multiple PCBs and thousands of components. This article addresses two of the mysteries of thermal analysis: power dissipation and thermal boundary conditions.

No matter how meticulous the analyst has been in creating the thermal model of the electronics box, PCB, and/or electronic components, the accuracy of thermal analysis ultimately rests on the accuracy of the component power dissipations provided by the PCB designer. In other words: garbage in, garbage out.

In many applications weight and physical size are critical, and if the component power dissipations are too conservative, thermal over-design will result. Thermal over-design refers to changes made in a PCB design in response to thermal analysis performed with unrealistic or overly conservative component power dissipations.

The opposite, and unfortunately more critical problem, is thermal under-design where the component temperatures predicted by analysis are lower than the actual temperatures including aerospace, automotive, and consumer electronics. If your competitor has invested time in accurately determining component power dissipations, the PCB thermal analysis will help produce a product that is as small, light and efficient as it can be. Avoid inefficient PCB designs with accurate thermal modeling and component power dissipations.

Recent trends in electronic industry are to develop thin, light and miniature form of electronic equipment. Life

span of electronic component greatly gets reduced due to high heat density in small and compact layout which results in job insecurity or failure of components. This reduces system reliability. This is the reason why the thermal design becomes important.

The complexity of PCB manufacturing has increased enormously, from double-sided straightforward boards with 100% through-hole technology to highly-complex multi-layer PCB's with mixtures of surface mount chip-on-board and through-hole configurations.

Board layouts have consequently increased in density with tighter tolerances and decreased distances between electrical contacts. Possibility of manufacturing defect increases with increase in complexity.

Thermal imaging is a method of improving visibility of objects in a dark environment by detecting the objects' infrared radiation and creating an image based on that information.

Night vision technologies that are most commonly used are near-infrared illumination, low-light imaging and thermal imaging. Thermal imaging works in environments without any ambient light. Fog, haze and smoke can be penetrated by thermal imaging just like near-infrared illumination.

Here's a brief explanation of how thermal imaging works: All objects emit infrared energy as a function of their temperature. Heat signature is the infrared energy produced by an object. More radiation is emitted as the object becomes hotter. Tiny differences in temperature can be detected using a heat sensor called as thermal camera. Infrared radiation is collected by the device from objects in the scene and creates an electronic image based on temperature differences information. Thermal camera can detect each object distinctly and can give a distinctive image as the objects that are closer very rarely have precisely same temperature.

Grayscale images are obtained using a thermal camera. Cold and hot objects look black and white respectively whereas variation between two is indicated by depth of gray. Different temperature is indicated by different colors in some thermal cameras.

II. PCB THERMAL IMAGE

The Thermal image of PCBs is taken using IR cameras. As it is taken in the controlled lab environment, the images are generally of high quality. The color – temperature scale (i.e. which color means how much temperature) is set in the camera. The temperature setting used for this analysis is shown here, with color 'black' representing minimum temperature of -40 °C and color 'white' represents the maximum temperature of 120 °C.

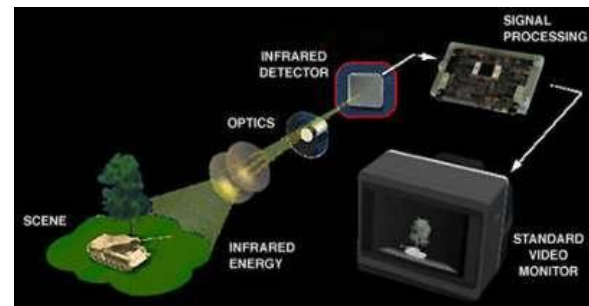


Fig 1: The basic components of a thermal imaging system.

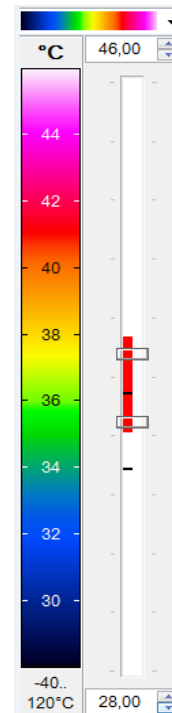


Fig. 2: Color – Temperature setting scale of the thermal camera.

Following explains the working of thermal imaging:

1. A special lens focuses the infrared light emitted by all of the objects in view.
2. The focused light is scanned by a phased array of infrared-detector elements. Thermogram is a detailed temperature pattern that is created by detector elements. Detector array obtains the temperature information to make the Thermogram with one-thirtieth of a second. Field of view of the detector array is the source of information.
3. The Thermogram created by the detector elements is translated into electric impulses.
4. The impulses are sent to a signal-processing unit, a chip is used for translating the information from the elements into data for the display.
5. The signal-processing unit sends the information to the display. Based on the intensity of the infrared emission, it shows different colors. The

mixture of all these signals from all of the elements creates the image.

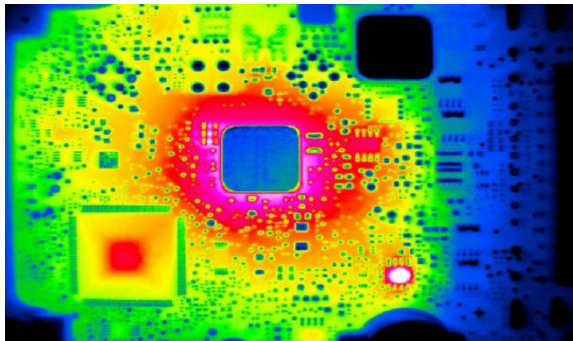


Fig. 3: Sample thermal image of a PCB with low thermal loading (evident from less white color).

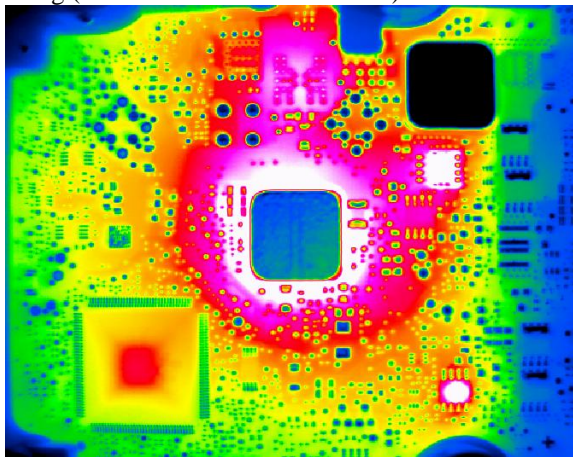
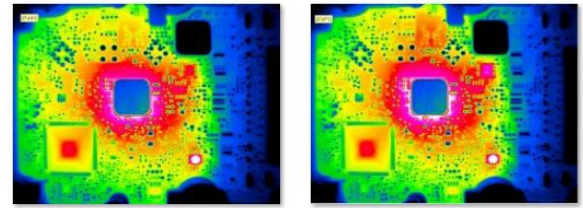


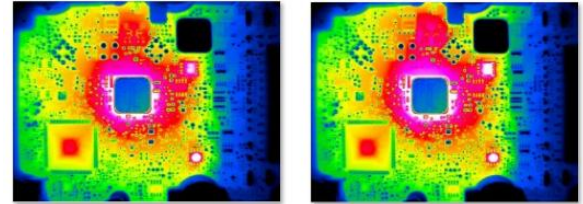
Fig. 4: Sample thermal image of a PCB with high thermal loading (as shown in white color).

In this project, we have taken a series of 20 thermal images stored in .png form as shown in figure 4. These are the images of the same PCB in different thermal load conditions. Each image corresponds to a particular electrical maneuver. The goal of the project is to develop a MATLAB based tool to aid the various aspects of image analysis.



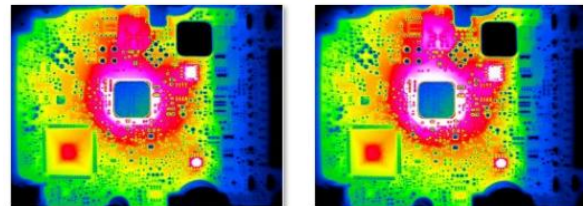
5

6



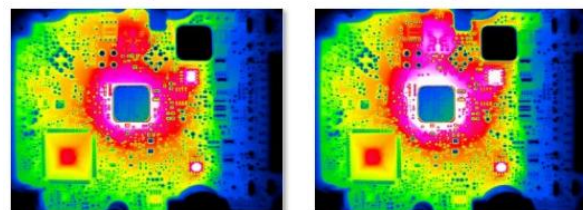
7

8



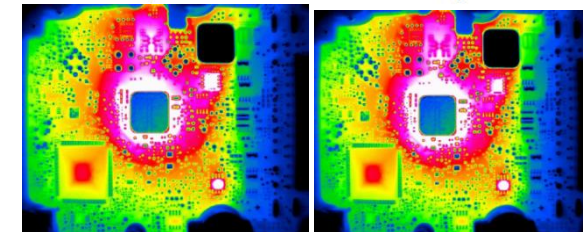
9

10



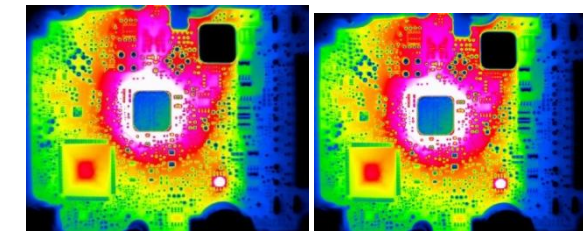
11

12



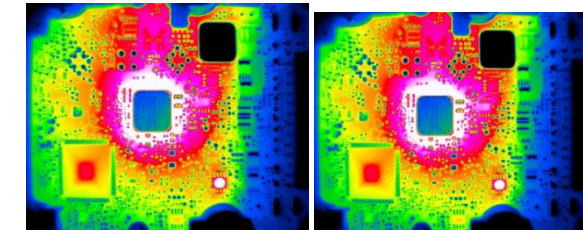
13

14



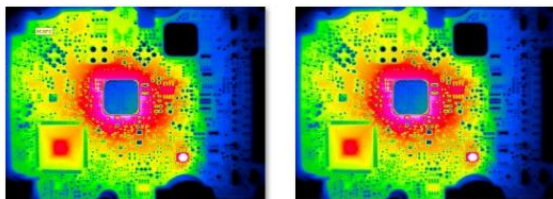
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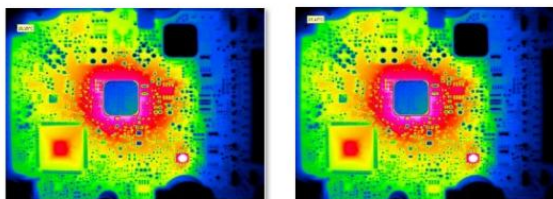
17

18



1

2



3

4

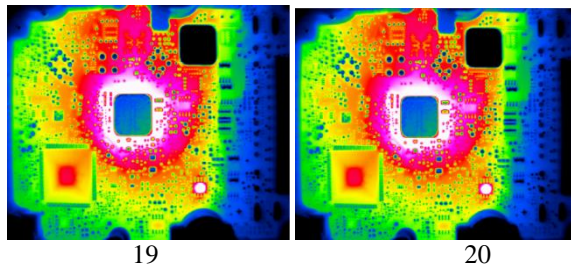


Figure 5: Input thermal images.

III. GUI

The GUI of this program provides the three options to the user to aide in thermal image analysis. Figure 5 shows a snapshot of the GUI developed.

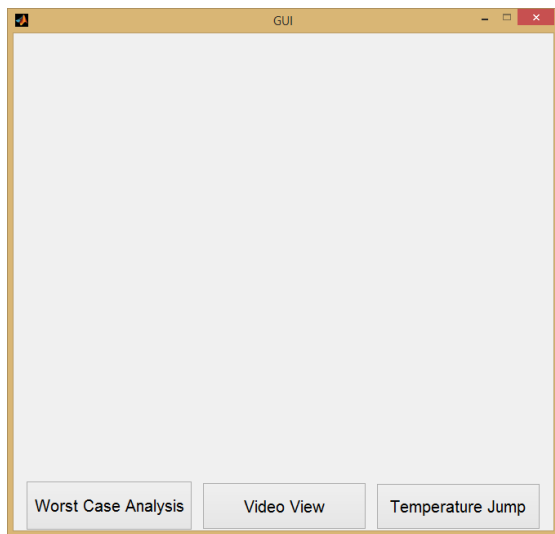


Figure 6: Snapshot of the GUI developed for this program.

The basic needs for analysis process are

1. Find out the maneuver with maximum heat dissipation – worst case analysis.
2. The amount of temperature jump between 2 selected instances
3. Possibility to view the thermal images as a video for visual inspection.

The methods incorporated to achieve all the above requirements are described in further chapters.

IV. WORST CASE ANALYSIS

It is desirable to know which image, and hence maneuver, is the most critical one. That means we need to identify the image having the maximum area of the peak temperature. This is achieved by using Histogram Thresholding based segmentation of the images.

HISTOGRAM THRESHOLDING FOR IMAGE SEGMENTATION

Image segmentation algorithms are based on one of two basic properties of intensity values discontinuity and similarity. Based on abrupt changes in intensity, divide

an image. Second type is based on dividing an image into regions that are similar according to some criteria. Histogram Threshold approach comes under this.

Threshold is one of the widely used methods for image segmentation. It is useful in differentiating foreground from the background. While choosing a proper threshold T , the gray level image can be changed to binary image. The converted image contains all of the actual knowledge about the position and shape of the objects of interest (foreground). The benefit of obtaining primary a binary image is that it reduces the complexity of the data and simplifies the process of recognition and classification. The general way to convert a gray-level image to a binary image is to select a single threshold value (T). Then all the gray level values below this T will be classified as black (0), and those above T will be white (1). The segmentation problem becomes one of selecting the proper value for the threshold T . A frequent method used to select T is by analyzing the histograms of the type of images that want to be segmented. The ideal case is when the histogram presents only two dominant modes and a clear valley (bimodal). In this case the value of T is selected as the valley point between the two modes. In real applications histograms are more complex, with many peaks and not clear valleys, and it rarely gives the proper the value of T . The threshold can be expressed as:

$$T=T[x, y, p(x, y), f(x, y)]$$

In this application, instead of converting the images into binary, number of pixels with intensity above the threshold of 250 for each image is obtained using the corresponding histogram. This count gives the size of the region with higher temperature. By comparing the sizes of hot regions between each image the image with largest hot area can be identified and in turn the maneuver causing this hot region.

The whole set of images are first read by the program and stored in unique variables. As each image is not of equal size, only the part of image of interest is restored by using 'imcrop' function. Since the standard histogram function 'imhist' of the MATLAB image processing toolbox does not work with RGB images, and the fact that our Region of Interest (RoI) is only of white color (which represents the temperature of 120°C and above as per the temperature scale of our thermal camera), we convert all the images to grayscale. Our RoI remains white and shades of white. Histogram of each of the images is calculated and stored. The program then compares each of the histograms and finds out the image with maximum number of pixels of white (band of pixels with intensity ≥ 250). This is the worst case image. This image is then displayed.

These are some of the results obtained after using wave menu function.

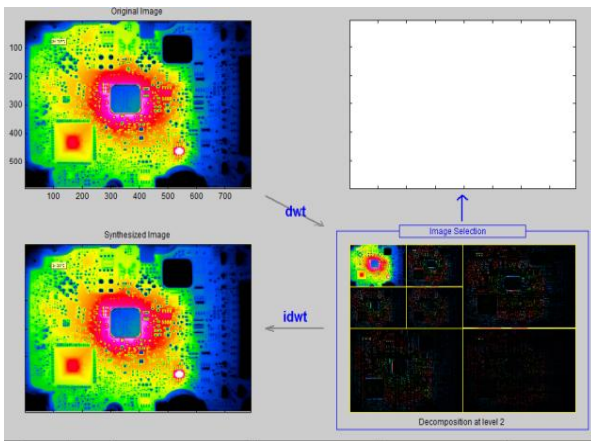


Fig 7: Synthesized image after decomposition.

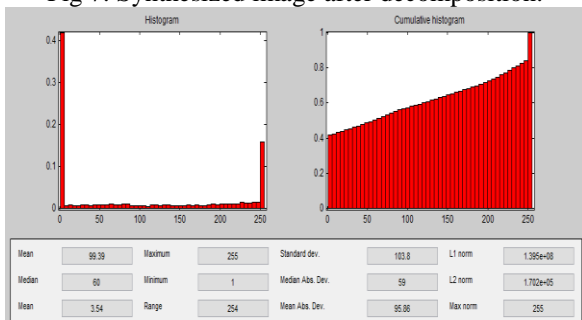


Fig 8: Histogram results and statistics of the image. Results obtained are shown in figure 9.

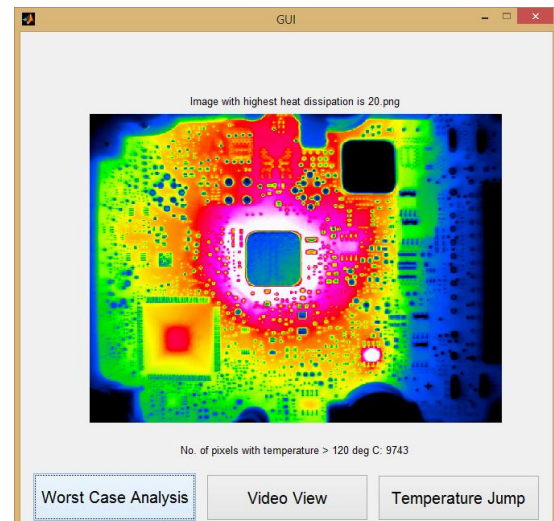
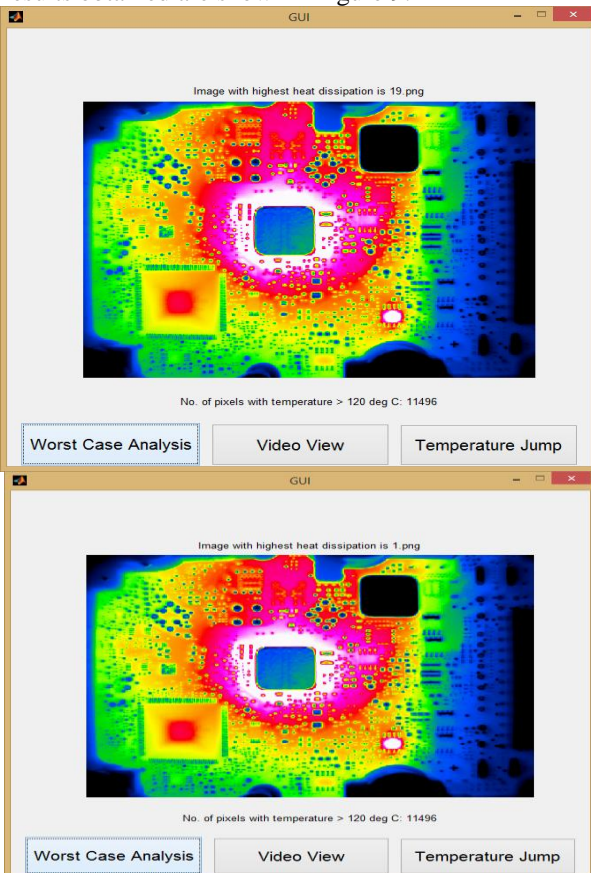


Figure 9: Results of worst case analysis.

- With original set of images 19.png has the maximum hot region and hence the result of worst case analysis displays 19.png with total number of pixels as 11496.
- By renaming 19.png as 1.png and vice-versa, the same image with same histogram count is display but with the changed filename.
- By removing 19.png in the original image set and the image with second largest hot area 20.png is displayed with the corresponding histogram count.

V. TEMPERATURE JUMP

As evident from the scale above, the white color here shows a temperature of 120°C, followed by pink and red. If there is just one image, or at max a few images, the manual analysis is easy. But normally we have a large number of such images. The consecutive images may have a slight temperature jump, or a significant jump, depending on the type of electrical loading.

In this case, as the images were of different size, the standard “imabsdiff” function of the MATLAB image processing toolbox does not work directly. Hence the images were first equalized by adding zeros to the smaller image to make it of same size as the bigger image. We added zeros because zero corresponds to black color which is a low temperature in our temperature scale. And low temperature is not of any interest in this analysis.

On selection of Temperature Jump option in the GUI, the program asks the user to enter the two image numbers between which the user is interested to see the temperature jump. The program then computes and displays the difference image between the two.

The figure 10 shows temperature jump between two images of close time interval. As it can be seen, most of the area in the difference image is black, meaning the temperature has not risen much between the two maneuvers.

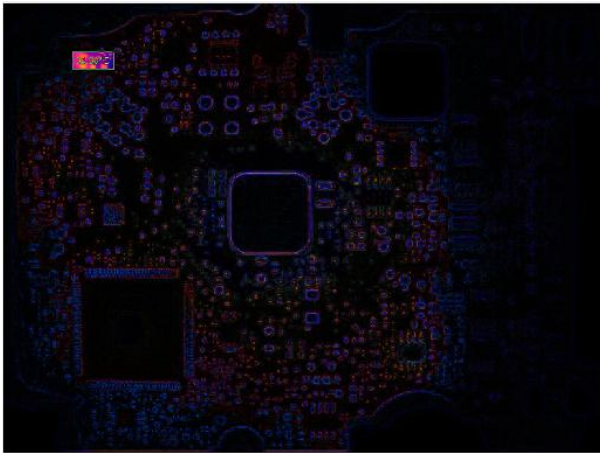


Fig 10: Difference image generated by the program for the close thermal events.

On the other hand, the figure 11 shows temperature jump between two images of significantly different temperature profiles. As it can be seen, there are colored areas in the difference image showing the temperature difference from the reference image.

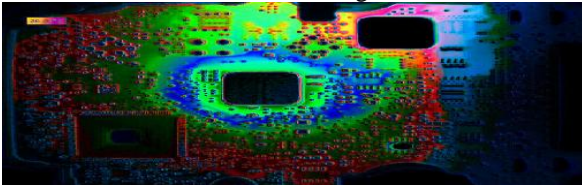


Fig 11: Difference image generated by the program for the significantly different thermal events.

VI. VIDEO VIEW

It is often very time consuming to view hundreds, or even thousands of images from an accelerated thermal test. To speed-up viewing of so many images, this program provides a MATLAB based tool to convert those many still images to a video file.

This is achieved by first converting each of the image to its corresponding frame using “im2frame” function of MATLAB. These frames are then joined to make a video using the “movie” function of MATLAB.

VII. CONCLUSION

This program shows an efficient way to make sense of the large number of thermal images. We provide a framework of the analysis and the program can be tuned to the specific needs. For example, the worst case analysis algorithm can also be adapted to view all the images having critical temperature spread of more than a set threshold. We can also generate a comparative report of the cooler areas on the PCB so that the high power traces could be routed in the cooler areas to have a more even heat spread across the PCB. By means of metadata of a file, the timestamps of each image can be collected and displayed in the output using which the maneuver can be mapped.

In this project total size of hot are is considered irrespective of whether it is at the microcontroller or at

power supply. With more complex PCB with more chips, choice to select region of interest should be allowed by having clustering based segmentation methods.

Though this program was developed for thermal image processing of PCBs, this uses the standard image processing methodologies like histogram thresholding technique, color based segmentation, histogram comparison, image difference generation and image to video conversion. The main problem addressed here is to draw meaningful conclusion from a large number of thermal images in very less time. Hence this program can be adapted for the image analysis of any other type of images where the region of interest is of a known color.

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