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Image Processing Based Defect Detection of Printed Circuit Board

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Abstract-- Visual inspection is one of highest cost in printed circuit boards (PCB) manufacturing. Although many algorithms are available in defect detection, both contact and non-contact methods none is able to detect the defects accurately. Contact method tests the connectivity of circuits but unable to detect major flaws in cosmetic defects. Non-contact uses methods such as ultrasonic and x-ray imaging to detect anomalies in the circuit design. The use of manual labor to visually inspect each PCB is no longer viable since it is prone to human errors, time consuming, requires large overhead costs and results in high wastage. Thus an automation inspection system is highly desirable. This project aims at demonstrating real time PCB Defect Identification using digital image processing. This does not involve using a specialized sensors attached to the PCB. Printed circuit defects are mainly missing or extra elements on the board. PCB defects can be categorized into two groups; functional defects and cosmetic defects. Functional defects can be fatal to the circuit operations while cosmetic defects affect the appearance of the circuit board but may affect the performance of the circuit in long term.
Index Terms—PCB, functional defects and cosmetic defects

I. INTRODUCTION

The PCB manufacturing process is based on chemical and mechanical actions that may damage the intended design. Frequently, various PCB defects such as break out, pin-hole, open-circuit, under-etch and mouse-bite occurred during production. Computer generated printed circuit board images absent from any defects, known as Template Images are designed as control images to compare with the circuit that contains defects, known as Test Images. It uses mathematical morphology and windowing technique. Morphological process involves techniques such as dilation, erosion, opening and closing which helps in partitioning the images and identifying the defects. Thus the PCB manufactured can be looked for flaws and if found defected can be moved out and the exact identification of the flaws will help in identifying the process in which the manufacturing defect occurred.

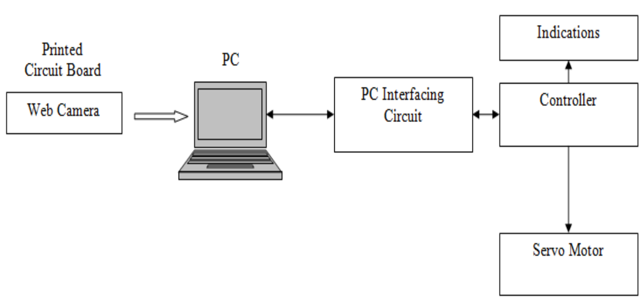

Fig 1:- PCB Defect Identification

Automatic optical inspection for the manufacture of PCBs is not a new problem. Image pattern recognition has been used commercially for many years in order to identify faults, and also for controlling the automatic placing of components onto circuit boards. However, most techniques currently in use are proprietary and designed for large-scale operations.
For small-scale manufacturers who have no access to complex vision technology or expensive vision systems, there are few realistic options. They are often forced to perform manual inspection which requires long hours of concentration. We propose an example of a modern PCB with many tiny components. Some of them can be smaller than 0.5 mm. It is difficult for human eyes to find problems, such as a missing component or a reversed component. The goal of this study is to develop a cost-effective solution for small-scale circuit board manufacturers. The solution should use relatively inexpensive hardware, introduce minimal delay to the

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manufacturing cycle through image capture and automatic fault detection, and greatly reduce the time spent manually inspecting circuit boards. In addition the solution should not rely on proprietary image processing techniques. It should not be sensitive to settings and not require frequent calibration or manual adjustment. Furthermore this solution should not be board-dependent, meaning the solution can be easily used for different types of PCB.

Our answer to the above requirement is a Genetic Programming (GP) based methodology. The basic idea is to evolve a program to learn the difference between what is normal and examples of faults, so it can report problems on new boards. GP is a powerful problem solving mechanism which has been successfully applied in many domains, especially where human knowledge is limited [1], [2]. Hence domain knowledge is not that essential in GP methods. Additionally GP represents a solution as a program tree which contains executable operators. So a GP tree has computational capabilities that can be used for extracting features and making decisions. This makes it possible for GP to work with raw image data rather than predefined features, as suggested by studies on complex computer vision problems such as texture classification [3], motion detection [4] and shot detection [5]. So the need for image processing operators can be eliminated. Another benefit of GP approaches is that the solutions evolved by GP are usually small in size, hence efficient in execution. So the detection process would not be time consuming. Existing studies on GP also show that GP solutions are often reliable. They can handle large variations which are not present during training such as noise or even a completely new situation [4].

Therefore we present a proposed GP methodology to address the PCB defect detection problem. The problems to be identified include missing components, misplaced components, incorrect components and so on. The data set used in this study consists of realistic circuit boards from genuine production runs, rather than toy examples. The images are taken with conventional photographic equipment with no special lighting or settings. This demonstrates the capability and reliability of our GP method. The rest of this paper is organized as follows. We begin with background work related to this study in Section II. The overall methodology is detailed in Section III. The GP representations proposed for this PCB defect detection problem is described.

II. SPECIFICATIONS

A. Hardware Components

1) Microcontroller – PIC18F45K22/ARM
2) PC Interfacing
3) Servo Motor
4) Web cam
5) PC

B. Software Tools

1) MPLAB IDE – For controller programming
2) OrCAD – For circuit design
3) Eagle – For PCB design
4) MATLAB for PC programming.

C. Advantages

1) Can be used to identify multiple faults
2) Can do the fault identification in real time
3) Reduces Manual Labor
4) Reduces lots of time and human error

D. Existing System

1) Uses X-ray or Ultrasonic
2) Manual Scanning is done

E. Proposed System

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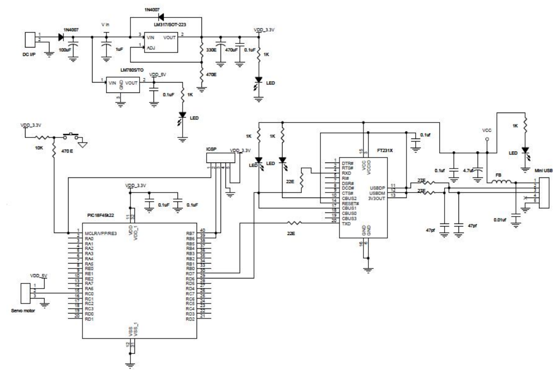
1) Uses image processing techniques so more accurate result is obtained
2) Finds both technical and cosmetic faults

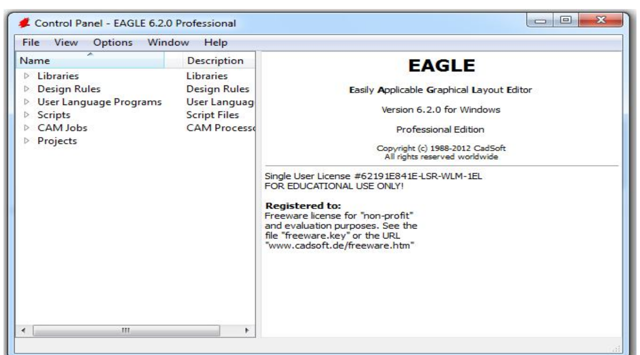
F. Circuit Diagram

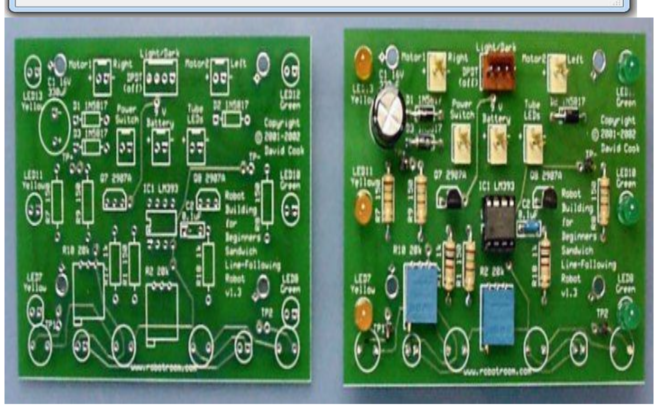


III. MODULE DESCRIPTION

A. Designing Module

1) *EAGLE – PCB Design:* A schematic or a circuit diagram is only a technical representation of a circuit design. However for actually constructing a circuit design into a physical board a PCB (Printed Circuit Board) is needed. A PCB is the base on which the different components are placed and soldered. The PCB contains copper traces or tracks that establish connection between the components placed on the board. The following picture shows a just a PCB and a PC with components placed and soldered in it.





Before a PCB can be physically fabricated it has to be designed to decide where all the components will be placed and arranged and

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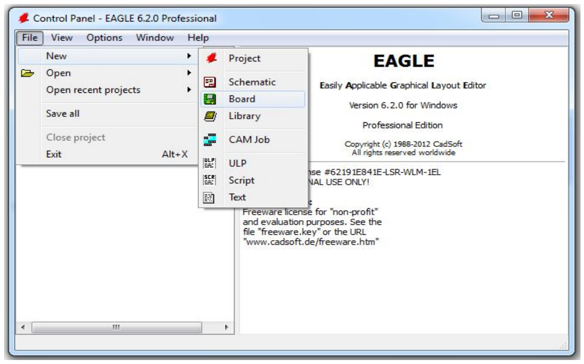
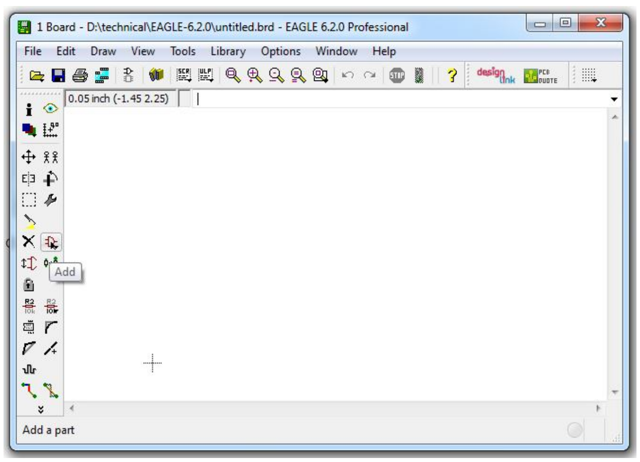
how the PCB traces will connect the different components. This process is called PCB design. There is different software available that can be used for PCB design. EAGLE (**E**asily **A**pplicable **G**raphical **L**ayout **E**ditor) is one such software created by the company called CADSOFT. EAGLE is a easy to use yet very capable software for PCB design. Hence it is the ideal choice for small to medium projects including student projects.

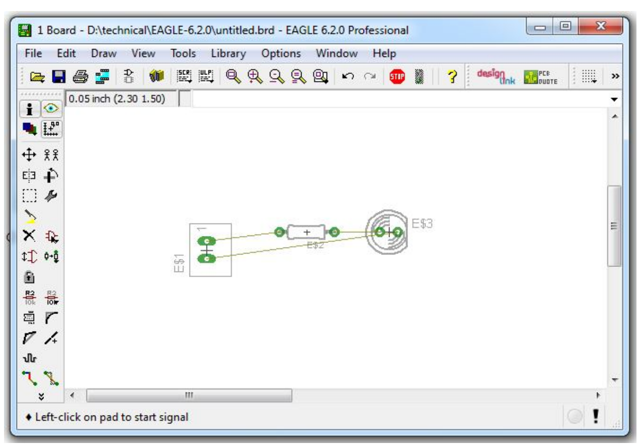
The following steps show the creation of a simple PCB design, beginning with the next step which is to start EAGLE.



2. Start a new PCB design by selecting board from the File >> New menu.



3. Start adding components to the design using the add button.



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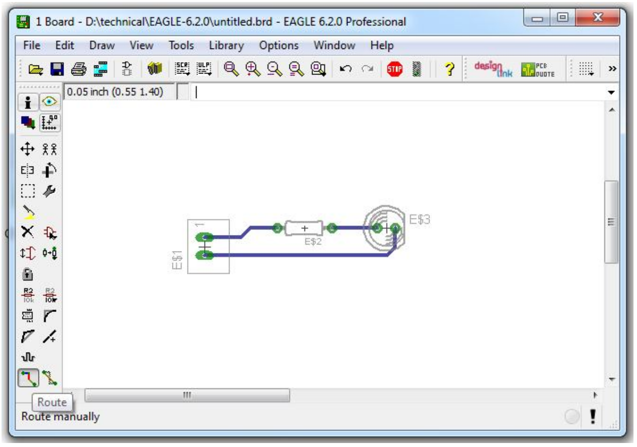
4. Connect the components using the Signal command, to establish the connection between them.

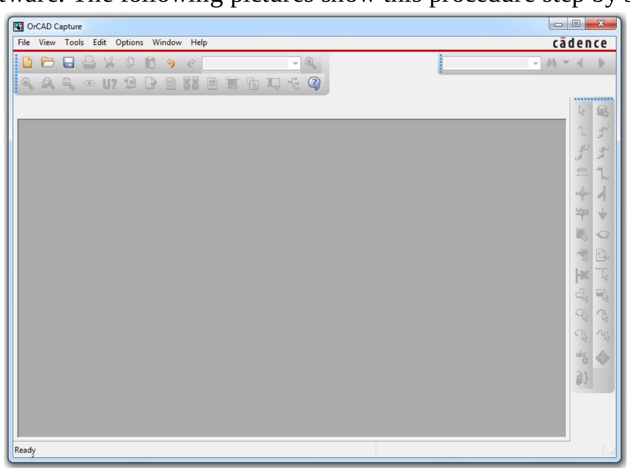


5. Draw the copper trace using Route command for small boards and use auto router for complicated designs.

B. OrCAD – Schematic / Circuit Design

OrCAD is an EDA (electronic design automation) software that combines different tools for various stages of a electronic circuit design. OrCAD has a tools for schematic design, PCB design and also simulation tools when the simulation models are available.

One of the tools in OrCAD is called Capture. OrCAD Capture is used for schematic design or circuit design. Capture is like most CAD based design software where the different components are provided as a library. The user can select different components needed for a design from the library and can add them to the circuit. Once all the necessary components are added they can be interconnected using wires in the software. The following pictures show this procedure step by step.



IV. POWER SUPPLY MODULE

Power supply is a device that transfers electric power from a source to a load using electronic circuits. typical application of the power supplies is to convert utility's AC input power to regulated voltage required for electronic equipment.

Basic Functional Units:

Most electronic circuits need a DC supply such as a battery to power them. Since the mains supply is AC it has to be converted to DC to be useful in electronics.

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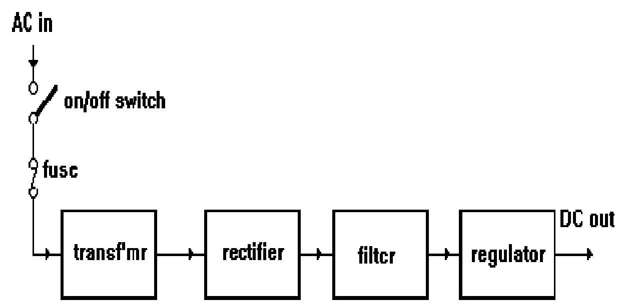
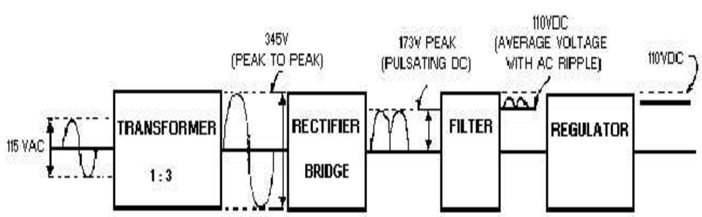
This is what a power supply does.



First the AC mains supply passes through an isolating switch and safety fuse before it enters the power supply unit. In most cases the high voltage mains supply is too high for the electronic circuitry. It is therefore stepped down to a lower value by means of a Transformer. The mains voltage can be stepped up where high DC voltages are required. From the transformer the AC voltage is fed to a rectifier circuit consisting of one or more diodes. The rectifier converts AC voltage to DC voltage. This DC is not steady as from a battery. It is pulsating. The pulsations are smoothed out by passing them through a smoothing circuit called a filter. In its simplest form the filter is a capacitor and resistor. Any remaining small variations can, if necessary, be removed by a regulator circuit which gives out a very steady voltage. This regulator also removes any variations in the DC voltage output caused by the AC mains voltage changing in value. Regulators are available in the form of Integrated Circuits with only three connections.

Each of the blocks is described in more detail below:
Transformer - steps down high voltage AC mains to low voltage AC.
Rectifier - converts AC to DC, but the DC output is varying.
Filter - Smooth the DC from varying greatly to a small ripple.
Regulator - eliminates ripple by setting DC output to a fixed voltage.
Working Principle:



B

The first section is the TRANSFORMER. The transformer steps up or steps down the input line voltage and isolates the power supply from the power line. The RECTIFIER section converts the alternating current input signal to a pulsating direct current. And the pulsating dc is not desirable. For this reason a FILTER section is used to convert pulsating dc to a purer, more desirable form of dc voltage. The final section, the REGULATOR, does just what the name implies. It maintains the output of the power supply at a constant level in spite of large changes in load current or input line voltages. Let us see in detail about the block diagrams in details.

Transformer: A Transformer is a device that transfers electrical energy from one circuit to another by electromagnetic induction (transformer action). The electrical energy is always transferred without a change in frequency, but may involve changes in magnitudes of voltage and current. Because a transformer works on the principle of electromagnetic induction, it must be used with

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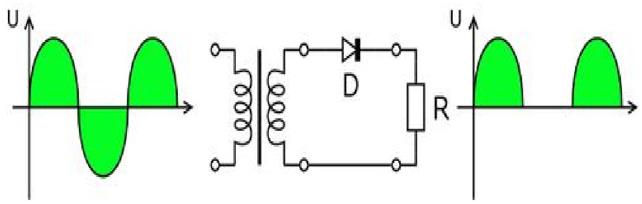
an input source voltage that varies in amplitude. There are many types of power that fit this description; for ease of explanation and understanding, transformer action will be explained using an ac voltage as the input source. The center tap transformer is used in the power supply unit. a center-tapped transformer and two diodes can form a full-wave rectifier that allows both half-cycles of the AC waveform to contribute to the direct current, making it smoother than a half-wave rectifier. A **center tap** is a wire that is connected to a point half way along one of the windings of a transformer, inductor or a resistor. Center taps are sometimes used on inductors for the coupling of signals, although most tapping are not at the center but usually near one end. In the case of resistors, tapping is usually done only with potentiometers, and center tapping is just a special case of normal operation of these devices.

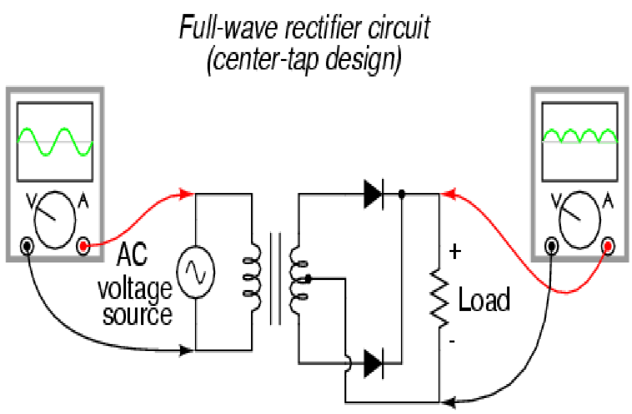
Rectifier: Rectification is the conversion of alternating current (AC) to direct current (DC). This almost always involves the use of some device that only allows one-way flow of electrons. As we have seen, this is exactly what a semiconductor diode does. The simplest type of rectifier circuit is the *half-wave* rectifier, so called because it only allows one half of an AC waveform to pass through to the load:

Half Wave Rectification: A half wave rectifier is a special case of a clipper. In half wave rectification, either the positive or negative half of the AC wave is passed easily while the other half is blocked, depending on the polarity of the rectifier. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half wave rectification can be achieved with a single diode in a one phase supply.



For most power applications, half-wave rectification is insufficient for the task. The harmonic content of the rectifier's output waveform is very large and consequently difficult to filter. Furthermore, AC power source only works to supply power to the load once every half-cycle, meaning that much of its capacity is unused. Half-wave rectification is, however, a very simple way to reduce power to a resistive load. Some two-position lamp dimmer switches apply full AC power to the lamp filament for "full" brightness and then half-wave rectify it for a lesser light output:

Full Wave Rectification: IN4001 is the diode that is used to construct rectifier. If we need to rectify AC power so as to obtain the full use of *both* half-cycles of the sine wave, a different rectifier circuit configuration must be used. Such a circuit is called a *full-wave* rectifier. One type of full-wave rectifier, called the *center-tap* design, uses a transformer with a center-tapped secondary winding and two diodes, like this:



This circuit's operation is easily understood one half-cycle at a time. Consider the first half-cycle, when the source voltage polarity

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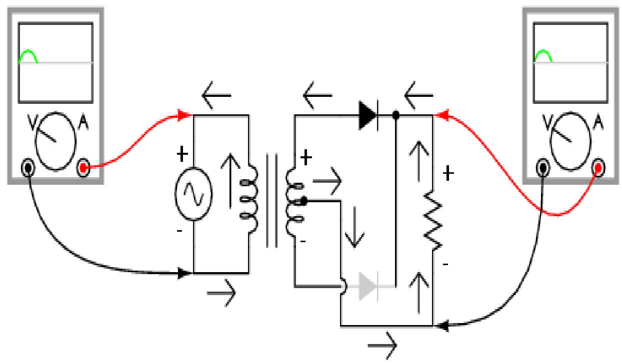
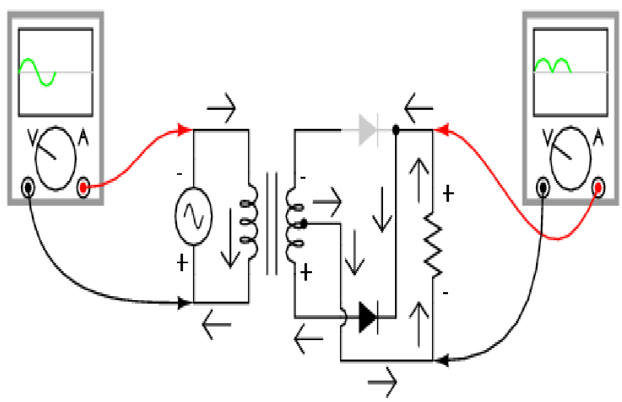
is positive (+) on top and negative (-) on bottom. At this time, only the top diode is conducting; the bottom diode is blocking current, and the load "sees" the first half of the sine wave, positive on top and negative on bottom. Only the top half of the transformer's secondary winding carries current during this half-cycle:



During the next half-cycle, the AC polarity reverses. Now, the other diode and the other half of the transformer's secondary winding carry current while the portions of the circuit formerly carrying current during the last half-cycle sit idle. The load still "sees" half of a sine wave, of the same polarity as before: positive on top and negative on bottom:



One disadvantage of this full-wave rectifier design is the necessity of a transformer with a center-tapped secondary winding. If the circuit in question is one of high power, the size and expense of a suitable transformer is significant. Consequently, the center-tap rectifier design is seen only in low-power applications. Another, more popular full-wave rectifier design exists, and it is built around a four-diode bridge configuration. For obvious reasons, this design is called a *full-wave bridge*:

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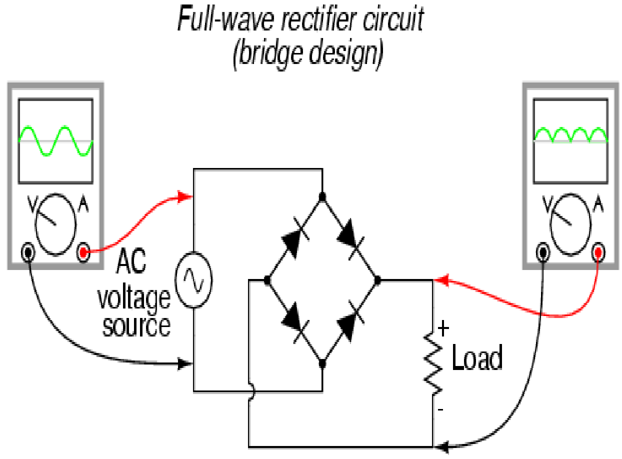

Current directions in the full-wave bridge rectifier circuit are as follows for each half-cycle. Here we do not use the full wave bridge rectifier circuit.

Filter: This DC is not steady from a rectifier. It is pulsating. The pulsations are smoothed out by passing them through a smoothing circuit called a filter. In its simplest form the filter is a capacitor and resistor.

Capacitor Filter: The simple capacitor filter is the most basic type of power supply filter. The use of this filter is very limited. It is sometimes used on extremely high-voltage, low-current power supplies for cathode-ray and similar electron tubes that require very little load current from the supply. This filter is also used in circuits where the power-supply ripple frequency is not critical and can be relatively high.
The simple capacitor filter consists of a single-filter element. This capacitor (C1) is connected across the output of the rectifier in parallel with the load. The RC charge time of the filter capacitor (C1) must be short and the RC discharge time must be long to eliminate ripple action when using this filter. In other words, the capacitor must charge up fast with preferably no discharge at all. Better filtering also results when the frequency is high; therefore, the full-wave rectifier output is easier to filter than the half-wave rectifier because of its higher frequency.
Regulator: 78L05 is the regulator is used for the regulation of the DC output from the filter. It produces 5V output
LM317 is the regulator is also used for the regulation of the DC output from the filter It along with a few resistors produces3.3V.
The LM78LXX series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment.
The LM78LXX is available in the plastic TO-92 (Z) package, the plastic SO-8 (M) package and a chip sized package (8-Bump micro SMD) using National's micro SMD package technology. With adequate heat sinking the regulator can deliver 100mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistors is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

V. CODING DESIGN (MATLAB)

```
clear all;
close all;
clc;
```

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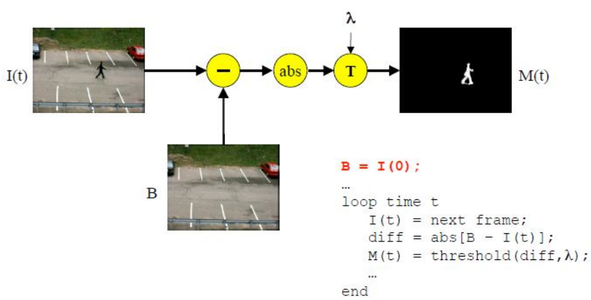
```
% Has area and centroid standard deviation
SetAreaDiff = 500;
%%
strelvalue1= 2;   %% increase this if more number of tracks are detcted than normal
strelvalue2= 5;   %% increase this if more number of tracks are detcted than normal
                  % Decrease these two if less number of tracks are detected than normal
%%
portnumber = 'COM3';
imaqreset;
disp('Switching On Camera....');
disp(' ');
%imaqhwinfo
vid = videoinput('winvideo',2,'RGB24_640x480');          % external webcam
%vid = videoinput('winvideo',1,'YUY2_1280x1024');        % internal webcam
% Set the properties of the video object
set(vid, 'FramesPerTrigger', Inf);
set(vid, 'ReturnedColorspace', 'rgb')
vid.FrameGrabInterval = 5;
%start the video aquisition here
start(vid);
preview(vid);
while(vid.framesacquired < 1)       %wait till first frame is over
end
disp('Capturing Started....');
disp(' ');
match = 0;
while(match == 0)
 quest = 'Please Any key to Acquire Image\n';
 keypress = input(quest, 's');
 close all;
 templatebit = 0;
 comp1 = strcmp(keypress,'Q');          % Press Q to terminate execution
if(comp1 == 1)
   imaqreset;
   disp('Quitting Execution -Terminated by user')
   match = 1;
else

   if(strcmp(keypress,'T') == 1)
      templatebit = 1;
   else
      templatebit = 0;
   end

   image = getsnapshot(vid);
   size(image)
   Input_image = image;
  % image = imresize(image, [500 500]);
```

```
image_gray =rgb2gray(Input_image);
figure(1);
imshow(image_gray);
title('Original Input Image')
%% Process the full PCB board image
image_gray_contrast = imadjust(image_gray);
figure(2);
imshow(image_gray_contrast);
title('CONTRAST ENHANCED IMAGE');
image_bw = im2bw(image_gray_contrast,0.6);
image_bw = imcomplement(image_bw);
se = strel('disk', 3);
image_bw = imclose(image_bw,se);
image_bw = imfill(image_bw, 'holes');
se = strel('disk', 5);
image_bw = imopen(image_bw,se)
```

VI. ALGORITHM

A. *Background Separation*

1) It removes the background from the captured image. Uses Frame separation method.
2) Take a single – empty frame as the Background model
3) Subtract the Background model frame with the current frame – The resultant frame will give only the object and remove the background. Compare the object with a threshold for proper object detection.
4) Background model is a static image (assumed to have no objects present).
5) Pixels are labelled as object (1) or not object (0) based on thresholding the absolute intensity difference between current frame and background.



B. *Track Extraction*

1) Normally in a PCB board, the tracks appear darker than the PCB board.
2) The algorithm uses this to identify the tracks and extract the tracks alone.
3) For this Thresholding Method is used. It also converts the gray scale image into the binary image.
4) In the binary image only the tracks appear and the rest of the board is eliminated.

C. *Thresholding Method*

1) Thresholding is the simplest method of image segmentation. From a grey scale image, thresholding can be used to create binary

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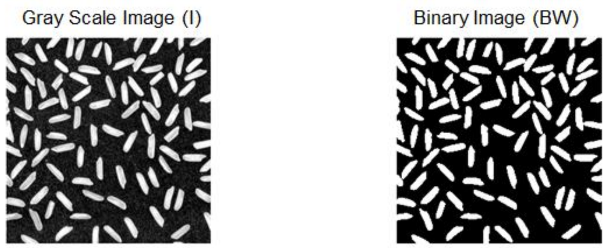
images

2) Image thresholding is a simple, yet effective, way of partitioning an image into a foreground and background.
3) This image analysis technique is a type of image segmentation that isolates objects by converting grayscale images into binary images.
4) Image thresholding is most effective in images with high levels of contrast.



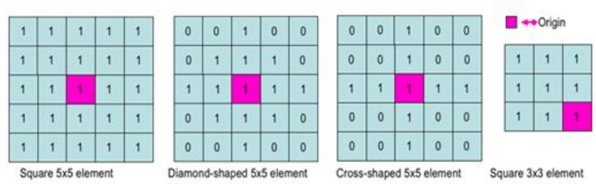
Example:
```
level = graythresh(I);
BW = im2bw(I, level);
```

1) Morphological Operations

2) The binary regions produced by simple thresholding are distorted by noise and texture.
3) Morphological image processing pursues the goals of removing these imperfections by accounting for the form and structure of the image.
4) Morphological image processing is a collection of non-linear operations related to the shape or morphology of features in an image.
5) Morphological operations rely only on the relative ordering of pixel values, not on their numerical values, and therefore are especially suited to the processing of binary images.

D. *Morphological Operations – Structuring Element*

1) The structuring element is a small binary image, i.e. a small matrix of pixels, each with a value of zero or one:
2) The matrix dimensions specify the *size* of the structuring element.
3) The pattern of ones and zeros specifies the *shape* of the structuring element.



E. *Track Fault Identification*

1) Track Fault identification uses blob analysis in which connected component analysis is used to find the track parameters.
2) Using the track characters such as size and number of tracks present in the image the faults in the track can be calculated.
3) Tracks can be classified as open-circuit, short-circuit or a normal track.

F. *Original PCB Layout*

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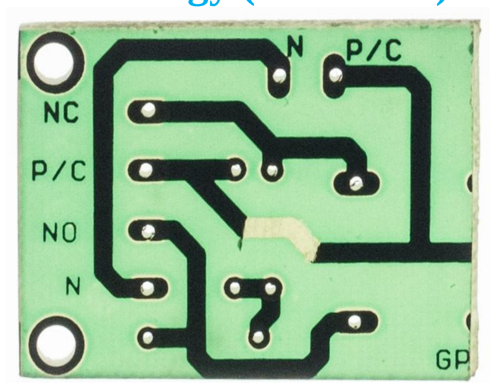

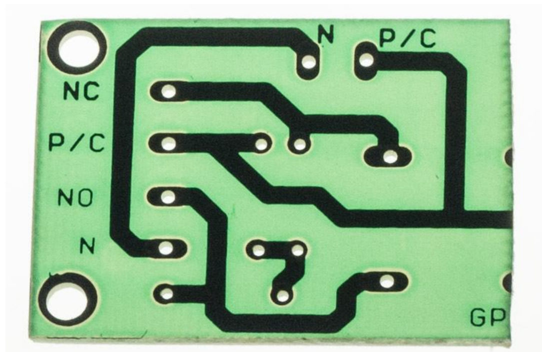

VII.CONCLUSION

This paper is presented and evaluated for PCB defect detection by image processing, a global leading cause for PCB's manufactured industries. This project aims at demonstrating real time PCB Defect Identification using digital image processing. The project involves the use of DIP and hence faults can be identified even before the components are soldered on the PCB. Multiple faults can be identified using the single image process and does not involve separate stages in the production line. Employs faster fault detection than conventional method.

VIII. ACKNOWLEDGMENTS

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