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Real time PCB diagnosis using FPGA - implemented video analysis tool

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***Abstract*— This paper presents a solution to diagnosis printed circuit boards in terms of wiring crossing, based on real-time image analysis. The image is captured using an ordinary video camera (web cam) that is placed above the board while a light source is placed under. The image is processed locally in the FPGA, and bright spots which indicate board cross are isolated. Through an Ethernet interface, the system allows the input "pattern" (correct PCB cross positions) to be compared to the processed image. The comparison can determine the exact position of the cross points and if it corresponds to the expected pattern. The system is meant to be an effective method of real time checking of the printed circuit boards' quality. For this paper we use the SoC circuit Zynq 7000 (XC7Z010).**

Keywords*— *Real time, FPGA, video analysis, PCB quality, automatic quality analysis

I. Introduction

Evolution of FPGA circuits has caused implementation of more applications on them. Basic image processing algorithms in respect to error correction and extracting objects is a type of application that is suitable to be implemented on FPGA circuits [1]. Thus we can obtain image processing results with very small delay compared to conventional methods which use microprocessors. The results of image processing like background extraction [2] or even image processing derived from multi-channels [3] is supplied in real time.

There are several works that use image processing for detection and identification of certain characteristics in real time. Maia spectroscopic detection system presented in [4] uses integrated tools for real-time spectral analysis of a bi-dimensional signal which resulted from a high resolution X-ray scanning. A recent paper published this year [5], deals with a system based on radar image analysis. The system uses an array of MIMO radio antennas (Multiple Input Multiple Output) and the captured radio image is analyzed by the DSP and FPGA. In modern applications image processing systems are generally focused on identifying movement and interpretation of certain positions of the human body placed in front of the camera, such as the interactive 360 degree display presented in [6] or the stereo image capture and viewing system in [7]. Potting (tracking) of objects through histogram is presented in [8]. In this example it a video processing core was implemented that can be used with other modules in a complete system. The method is completely autonomous and implemented in FPGA with application in automated video surveillance systems. There are many areas in which a noninvasive detection by image analysis solution is preferred problems such as automotive applications [9].

Our paper presents a method of real-time assessment of the quality of printed circuit boards (PCB diagnosis) using image analysis. A diagram of our system is shown in the figure below (figure 1).

The image is captured with an ordinary video camera. The ARM-based processor on the SOC is responsible for taking frames and sending them to the FPGA. A static frame is transmitted through the XillyBus dedicated interface to FPGA where a line by line analysis of the picture is performed and bright dots are extracted. The results are the coordinate values of cross points (using bottom and top of board as references and scaling entire picture). The circuit evaluation consists of a comparison between the circuit pattern (set with correct cross point's positions) and positions of the bright points in the image.

II. System Presentation

This section describes the system that identifies the image analysis problems: first the system will be presented overall and then each real time image processing component module will be detailed.

A. System operation

First of all, Figure 1 shows the operating mode of the system, as well as its block diagram. The system is based on the Xilinx Zynq 7000 SoC. It contains, on the same wafer of silicon, a processor (programmable system called PS) and an FPGA (programmable logic called PL). The processor (ARM Cortex A9 866MHz) is used to acquire images from the camera via the USB port. The processor runs an operating system (Xilinux) containing the USB protocol for reading images from USB camera and turning them into image files which can then be processed. It then runs an application that allows reading of the image file and transmitting its data, pixel by pixel, to the image processing logic unit (PL), through XillyBus interface. At the same time, and pattern images containing proper distribution of viases through a PCB circuit - namely Gerber files containing the vias coordinates - are also being sent. They are provided through a web interface system (developed in PHP). The Gerber-load system, as well as the image acquisition and transmission to the programmable logic are both located in the processor part of the system. Beyond XillyBus interface is the FPGA module (Artix 7). It contains the image processing algorithms shown in more detail in Figure 2 and described in the next section. This takes the image of the PCB and compares it to the correct coordinates given in Gerber files while signaling possible mismatches.

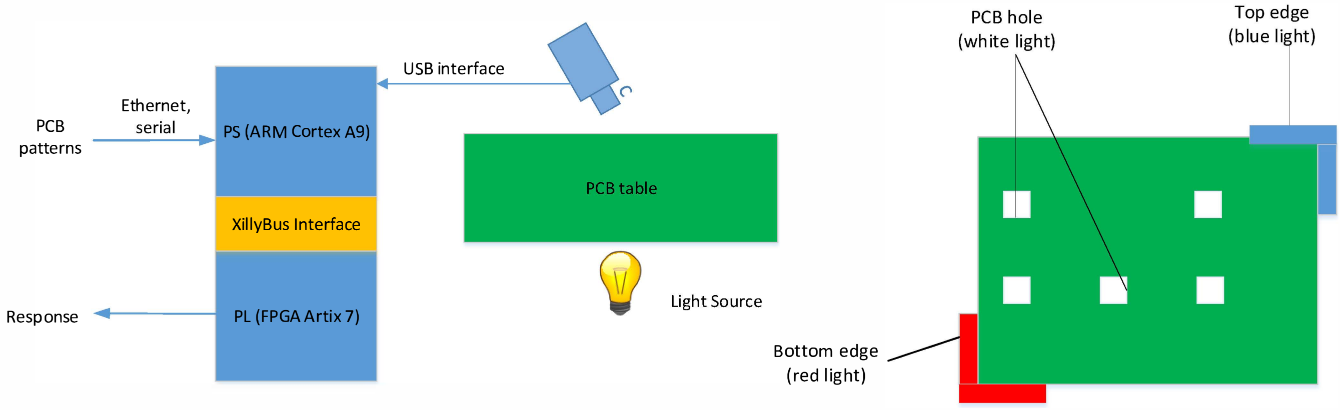


Fig.1 System block diagram (left) and PCB light distribution (right)

The camera is positioned to take a picture of the PCB (experimental size is 20 x 10 cm). In order to correlate the image to the supplied Gerber coordinates, the first step is an image to Gerber calibration by using two marks (figure 1 right). The two marks points to the lower left and the upper right part of the PCB. By knowing the exact PCB size (fixed in our experiments) the image to Gerber scale can be easily determined.

Both the marks as the vias are detected through the utilization of a light source placed behind the PCB. The two marks are actually two color filters (red and blue) placed and the edges of the board, while de vias will be captured as white light points. By using distinctive colors, the image analysis is easier to implement.

B. Programmable logic components

System hardware consists of the digitally implemented FPGA modules shown in figure 2. Together they work on color information extraction rom the pixel level in order to identify the vias position on the PCB image. Figure 2 depicts the usage of more memory blocks of different types. First of all, a buffer is used to store the information from a image line. The information is received byte by byte from the processor and is written into a FIFO-RAM memory with bi-port access.

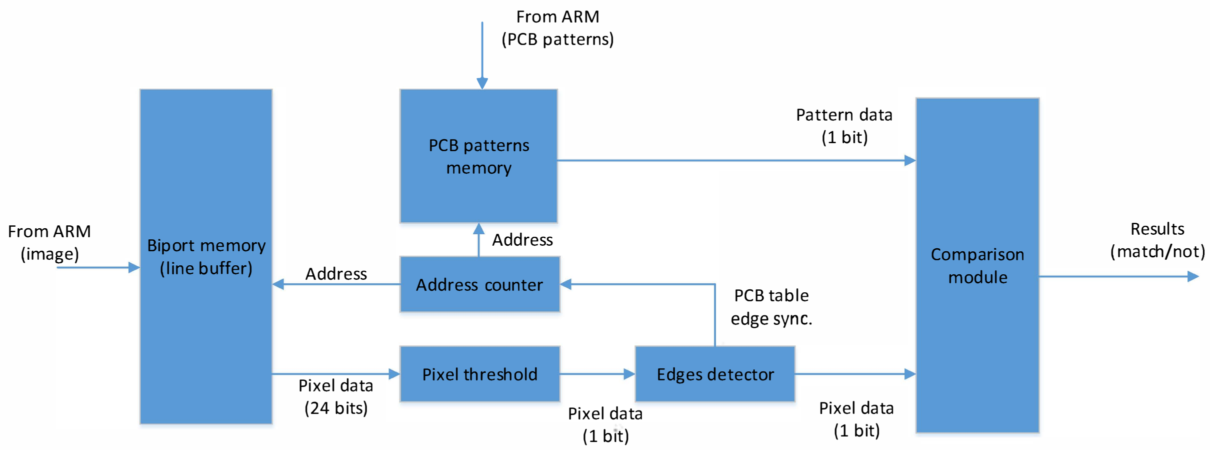


Fig.2 Programmable Logic block diagram

On one hand, the processor stores the information in a stack while on the other hand an address counter has the address of the desired information's location. The information is extracted pixel by pixel from the line-buffer memory. It is then fed to a threshold comparison module which identifies 4 distinctive types of information (4 level image segmentation): red, blue, white or color. When red or blue color is identified a mark pixel is found. This information is transmitted to the edge detector. When white color is identified its position is compared to the one specified in the Gerber-file.

A random access memory is used by the processor to virtually places the corresponding discovered vias coordinates. Basically, in this memory we recreate a virtual PCB as a matrix of 0s and 1s. This memory is a bi-port as well and is accessed using the same address counter as above. The counter assures the synchronization between the Gerber-generated, correct image and the image the camera saved.

Address counter synchronization is made using the edge detection module. When a line from the actual image visited, the corresponding line from the virtual PCB is also visited. Detecting a vias on the image (white pixel) is compared to detecting a vias on the Gerber-generated PCB.

III. Experimental results

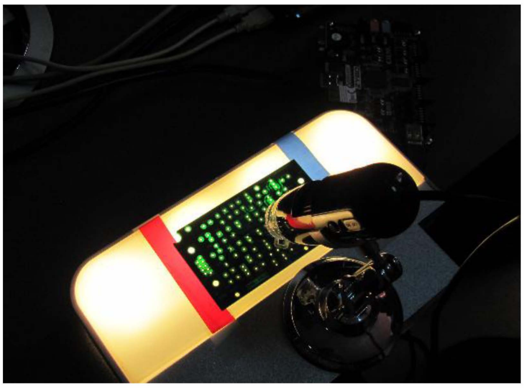
The experiment was conducted using a circuit Xilinx Zynq 7000 (XC7Z010). This module contains both a microprocessor (ARM Cortex A9 with an operating system installed: Xillinux) - representing Programmable System (PS) and an FPGA module (Artix 7) which represents Programmable Logic (PL). On the ARM microprocessor, the image has been captured and then sent to the FPGA interface using default configured XillyBus interface. Transmission is achieved through an application built within the project that takes the captured files, extracts information from them and transmits RAW image to the FPGA. Over FIFO8 interface (contained in XillyBus) a bi-port BRAM memory is mapped. It is visible to the PS as an 8-bit FIFO stack while at the PL as a random access memory. All the capture and processing can be automated so that the video stream reaches the FPGA directly from the camera - without being stored as image file.

In this article the author tested the system by verifying three types of PCB boards. For each type of PCB three actual boards exist: one board is broken while the other two are good. The fault is considered that that the vias are not opened, but filled in the manufacturing process. The board size is 20 x 10 cm. A total of 9 measurements were conducted, where the faulty boards were identified.

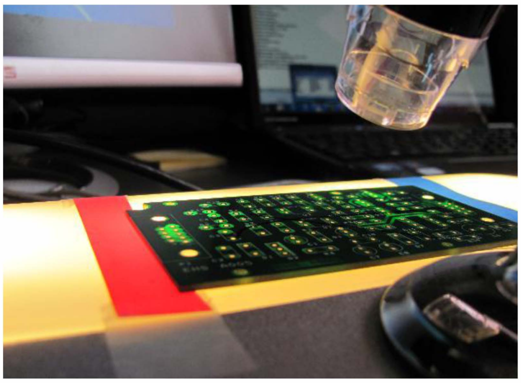
In this phase of the project the system provides an estimated processing time (from the moment when a picture is already stored in ARM memory) of about 38 ms, distributed as in the table below:

TABLE 1 TIME ESTIMATION FOR PCB DIAGNOSIS SYSTEM

Pixel	Read clock (from memory) = 20 ns/pixel	Pixel threshold delay (level comp.) = 10 ns	Edge detector (level comp.) = 10 ns	Comparison module = 2 ns
Frame / PCB image	Read entire image = 18.432 ms	Compare all pixels from frame = 9.216 ms	Compare all pixels for edge = 9.216 ms	Maximum 1.843 ms for all pixel
Diagnosis time (after image is loaded)	TOTAL			38.707 ms



a) Top picture with the system. PCB table with red and blue mark. In top right of picture is Zybo board with Zynq 7000 SoC, in center is video camera



b) Video camera while take a snapshot of PCB board. The photo of the board will be compared with Gerber file

Fig. 3 Pictures with experimental system

The camera used is an ordinary web cam. The images that are working are 1280 x 720 (720p) resolution. For a two layer board with 20x10 cm length we can detect hole with minimum diameter of 0.2 mm and distance of 0.5 mm. Using real time, non-invasive image analysis method of detecting PCB faults that may occur during the manufacturing process is the novelty brought to our paper.

IV. Conclusions

The system created by the authors allows detection of vias and comparison of their coordinates with the coordinates specified by the Gerber files. This is a non-invasive method detect manufacturing faults of PCBs. It is based on real time image analysis.

The authors' solution can be integrated into PCB verification systems. The circuits used are middle price SoC integrated circuits. Besides identifying vias through image analysis, other measurements of problems that may appear on PCB manufacturing can be taken: identifying holes and viases to boards with more than two layers, signal integrity and other aspects.

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