Automatically Recognizing Manufacturing Defects in TFT-LCD Panels by Image Inspection

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Abstract **—** Detecting manufacturing defects in assembly lines is fundamental for yielding final products of good quality. This paper presents a platform developed for automatically recognizing manufacturing defects in TFT-LCD panels by performing automatic image inspection.

Keywords — *TFT-LCD inspection, quality control, image recognition, defect patterns, manufacturing.*

I. INTRODUCTION

The detection of defects at the consumer end besides having a very high cost, largely damages the reputation of manufacturers. In home burn-in is also very expensive and if made by humans is a very error prone task. Quality inspection of parts before final product assembly is a strategy that allows an “as early as possible” defect detection. In general, such tests are made sampling batches of parts. Very frequently, parts of products are provided by several different manufacturers; it is also important to assess the quality of the different items of each of the part suppliers.

Flat-panel displays using Thin Film Transistor-Liquid Crystal Displays (TFT-LCDs) technology offer full-color display capabilities, low power consumption and light weight. Due to their excellent quality-cost balance they are increasingly more used in home-theatres, computer displays, etc. The inspection of defects in TFT-LCD panels is a critical task in manufacturing such goods. Surface defects of a TFT-LCD panel not only cause visual failure but also cause electrical failure to operate the panel. Nakashima [1], classifies the defects in TFT-LCD panels as *micro* and *macro*. Micro defects include pinholes, fingerprints, particles and scratches. Micro defects are generally very small in size, and cannot be easily found by human personnel or detected with electrical methods. Macro defects include the unevenness of color on a TFT-LCD panel, stains, and misalignment of a panel. They appear as high contrast regions with irregular sizes and shapes. They are generally large in size and, therefore, can be detected by human inspectors.

Visual inspection is an important and labor-intensive part of quality control in TFT-LCD manufacturing. Because of the TFT-LCD end-user-applications, 100% defect inspection is common practice in the manufacturing processes [2]. Currently, human visual inspection is the most commonly used method for LCD surface defect detection. However, manual inspection is slow, subjective, costly and highly dependent on the operator’s experience. Human inspection is a bottleneck in the TFT-LCD manufacturing process. Thus, to ensure TFT-LCD mass production quality, automatic defect inspection is required. The Samsung Electronics Manaus assembles 26,000 products per day using TFT-LCD panels from ten different manufacturers. The total number of defects found under human visual inspection in 2014 was 1,777; of which 1,242 were image ones such as vertical/horizontal line/blocks, stained images, etc. The remaining defects were mechanical (scratches, broken glass, etc.). Figure 1 presents the number of image defects found in the burn-in phase during the year of 2014 (the name of suppliers was omitted).

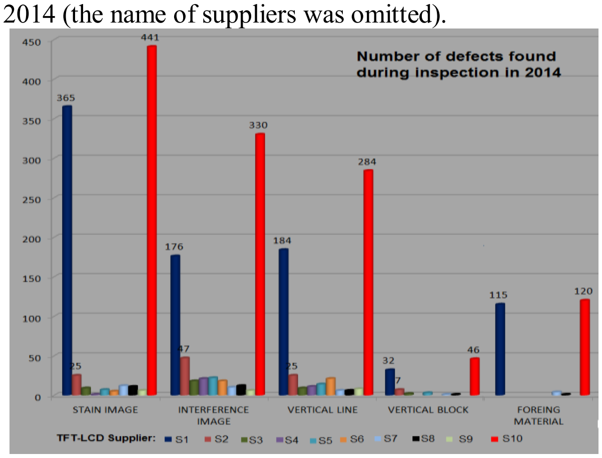

Fig.1 – Defects found during burn-in in 2014 at Samsung plant in Manaus, Brazil

This paper presents the prototype of a new platform for automatic TFT-LCD defect inspection, based on image recognition techniques.

II. RELATED WORKS

There is a broad range of techniques have been used to detect and classify defects in TFT-LCD panels [3][4][5][6]. According to Weiss and Saranli [7], the techniques belong to the three broad categories: electrical, optical and eletro-optical. Electrical and electro-optical techniques require the subject of inspection to have some measurable electrical or electromagnetic properties. This is the case for the primary several electrical and optical based inspection techniques available for TFT-LCD defect inspection. The panel can be excited by electrical means, and the resulting electrical or electromagnetic behavior be measured, recorded, and compared with the known normal behavior to determine the presence or absence of abnormalities in the subject being inspected. For these techniques, the physical size or visibility of the defect causing the electrical and/ or electromagnetic anomaly is often not a limiting factor for detection. The defect is detectable if there is a measurable impact on the electrical and/or electromagnetic behavior of the circuit on the subject being inspected. Other anomalies, independent of size, are missed by the inspection system. In addition, some of these defects may affect an area which is much larger than the physical defect size [7]. Hence, in some common cases, an electrical or electro-optical inspection technique would detect a defect signature which does not necessarily correspond to the physical defect that is the source of the anomaly on the subject being inspected.

References [8] and [9] presented an optical charge sensing technique for the inspection of active-matrix LCD panels. Charge sensing writes a charge to the storage capacitor at the individual TFT array pixel. The charge is read back and compared with the write charge to determine if the pixel is defective [4]. In reference [2], Henly and Addiego used the voltage-imaging technique to test the characteristics of a TFT-LCD array by directly measuring the actual voltage distribution on the TFT pixel and not at the storage capacitor. The advantage of the optical charge and voltage imaging approaches is that each pixel on the TFT panel can be individually tested. The main disadvantage of such approaches is that the probes used for voltage measurement must be separately designed for each panel configuration. References [10] and [11] claim that with the fast development of LCD technologies, the new-generation polysilicon TFT-LCD displays with integrated drivers need no storage capacitors. Thus, the charge-sensing and voltage-imaging methods will become useless since they cannot test arrays without storage capacitors.

A few vision-based techniques were developed for LCD defect inspection. The processing algorithm is typically either a computationally intensive pattern matching, or a more straightforward differencing method [5]. In 1994, Nakashima [1] presented an inspection system based on image subtraction and optical Fourier filtering for detecting defects in an LCD color filter panel. The image subtraction method was utilized to detect white and black defects such as black matrix holes and particles, and the optical Fourier filtering was applied for grain defects. Sokolov and Treskunov [13] developed an automated visual system for final inspection of LCDs. They compared brightness distributions between a reference LCD image and a test image to detect anomalies in the surface. The existing vision-based techniques generally need a pre-stored reference image for comparison. This requires large data storage for the reference image and precise environmental controls such as alignment and lighting for the TFT-LCD panel under inspection. Oh and his colleagues [14] studied the detection of line-type defects in TFT-LCD panels. In a low-resolution image, a directional filter bank (DFB) that finds directional information is used to identify horizontal or vertical line-shaped defects. In a high resolution image, a multi-level thresholding technique based on a statistical approach is employed to detect abnormal line defects that are brighter or darker than the surrounding pixels. Their approach is only applicable to line-shaped defects.

The vision-based techniques mentioned previously are based on the analysis of grey levels in two-dimensional area images. Today, there is an ongoing widespread demand for large-screen TFT-LCDs used in PC monitors and TVs, a market of several billion dollars a year. For automatic visual inspection of TFT-LCD panels, very high-resolution image acquisition is mandatory. Tsai and Hung [15] pioneered the use of a high resolution line scan for the inspection of large-sized TFT-LCD panels. They present an automatic visual inspection scheme that identifies defects directly from one-dimensional (1-D) line images of TFT-LCD panels. Their platform use a 60 pixels/mm resolution and they claim that it is capable of detecting micro-defects including pinholes, scratches and particles in TFT-LCD panel surfaces. For each horizontal scan line, the distance between two adjacent peaks in the grey-level line image corresponds to the spacing between two neighboring vertical data lines. Each scanned line profile exhibits periodicity and regularity properties. In the Tsai and Hung scheme [15], the problem of defect detection in TFT-LCD panel surfaces is considered as the identification of anomalies in a periodic 1-D grey-level signal. Their method does not rely on the design of quantitative features to describe local anomalies, nor does it require a reference template for comparison. It is based on an image reconstruction scheme that directly works on the 1-D input images using the 1-D Fourier transforms. It fully utilizes the inherent geometric structure of TFT-LCD panels. It first eliminates the frequency components that represent the periodic peak pattern of the 1-D grey level profile of a TFT-LCD line image in the 1-D Fourier spectrum, and then back-transforms the 1-D Fourier-domain image using the 1-D inverse Fourier transform. The Fourier reconstruction process can effectively remove the background of periodic peaks and distinctly preserve local anomalies in the resulting 1-D image. For a faultless TFT-LCD line image, the reconstruction process will result in a flat horizontal line. Conversely, high fluctuation of a line will be generated in the reconstruction for a defective TFT-LCD line image. The simple statistical process control limits can then be used to set up the thresholds for distinguishing between defective segments and uniform background in each reconstructed 1-D line image. A line image of a faultless region in the TFT-LCD panel surface will become an approximately uniform grey-level profile, while the line image of a defective region will be distinctly preserved in the reconstruction.

The Tsai and Hung scheme [15] uses the Haar wavelet [16] frame decomposition to remove the effect of uneven illumination in the test environment. Finally, simple 3-sigma control limits are employed to segment the highly deviated elements (i.e. defects) from the uniform background in the decomposed detail part of the Harr wavelet frame. Their method mainly aims at the detection of various micro-defects in TFT-LCD panel surfaces, but they do not classify the types of detected, an important feedback to be provided to suppliers to improve the quality of their products.

Purely optical inspection techniques, referred to as auto mated optical inspection (AOI), can both detect and locate defects independent of their electrical properties, provided they are visible under the chosen optical setup. Today, the technology of cameras and the processing speed of computers allow even small defects to be detected in a reasonable amount of time to be used in the automatic product lines of manufacturing plants. The platform presented here takes advantage of such technological advance and provides a low-lost high quality and throughput solution to the problem.

III. Platform Outline

The platform developed for image acquisition is camera-based. As already mentioned, the light sources from the environment may interfere in image acquisition, thus the TFT-LCD under inspection goes through a closed "box". A number of engineering details were observed in the development of the prototype platform, including: how the panel will be connected to the mains power source, how to insert the tested panel in the chamber, having a platform that can work with all the panel sizes of the different products, not damaging the panel or its finishing during testing, etc. More than one camera is used to provide adequate image resolution. The platform should automatically identify the size of the panel. The cameras work independently. The steps performed are:

1. Image acquisition by the cameras.
2. Definition of the region of interest (frame detection and image merge).
3. Feature extraction.
4. Image analysis and decision making.

Frame detection follows a straightforward scheme in which pixel color is analyzed. The height and width of the images captured allows to easily detecting the panel dimensions and how the two images are merged.

A "dot" is defined as a sub-pixel of each Red, Green or Blue component of the image. Feature extraction is performed both taking the RGB and gray-scale images. For each RGB component the intensity of pixels is analyzed and the mean and standard deviation are calculated. The same data is collected for the gray-scale image. For each panel size, there are reference values. If a panel presents any measure 5% higher or lower than any of the values of reference, the panel is rejected. Besides that each panel depending on its size must observe other restrictions. For instance, the following criteria must also be met for TFT-LCD panels of 65":

Bright dot: defined as dot, which appears bright on the screen when the LCD module displayed a black pattern.

1. The maximum number of bright dots allowed is one per R, G, and B component.
2. No adjacent bright dots are allowed.
3. Any bright dot seen at gray scale 0 up to 63 is supposed to be ignored.
4. Any bright dot seen at gray scale 64 up to grayscale 127 is acceptable within the maximum amount of 5 dots.
5. Any bright dot seen at gray scale 128 or higher gray scale is counted as a bright dot.

Dark dot: defined as a dot (sub-pixel) that appears dark on the screen when the LCD module display at bright pattern.

1. The maximum number of bright dots allowed is 8 in R, G, and B components.
2. Adjacent 2 dark dots (horizontal and vertical): maximum 2 pairs allowed.
3. Adjacent 3 dark dots (horizontal and vertical): 0 pair allowed.
4. Minimum distance between dark dots: 5 mm

Total amount of dot defects: the maximum number of dot defects in a panel is 8.

Currently, Samsung is analyzing the possibility of patenting the platform developed, thus technical details such as the number of cameras in the array, the manufacturer and model of the cameras used, distance between the cameras and the panel, etc. are not provided in the current version of this paper. Its final version should convey such details as in that moment the patent was already deposited.

IV. Experiments and Results

The defects detected are split into four classes:

P (positive): good panel recognized as such
FP (false positive): panel with defect, not recognized.
N (negative): panel with defect recognized as such.
FN (false negative): good panel, recognized as faulty.

The kinds of defects analyzed and the confusion matrices obtained for the different sizes of TFT-LCD panels are presented below. The occurrence of more than one defect simultaneously, although very rare, must be taken into account.

A. Vertical lines/blocks

Figure 2 presents the defect of "vertical line" that may appear in any part of the TFT-LCD and that may be of width of one (line) or more pixels (block).

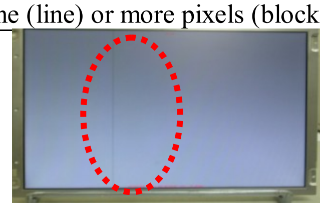

Fig. 2 – Vertical line defect in TFT-LCD panel.

The recognition results are shown in Table 1.

Table 01 – vertical defects

PANEL	P	FN	FP	N	Total
TV 58"	15	-	-	4	19
TV 55"	8	-	-	3	11
TV 48"	7	-	-	5	12
TV 46"	9	-	-	8	17
TV 42"	5	-	-	5	10

B. Horizontal lines/blocks

Figure 3 presents an example of a panel with the "horizontal line" defect. The recognition results obtained are presented in Table 02.

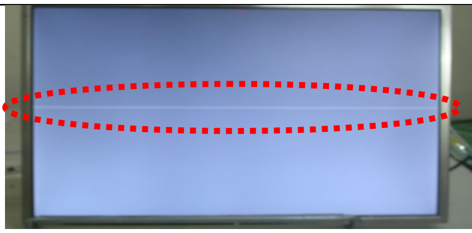

Fig. 3 – Vertical line defect in TFT-LCD panel.

Table 02 – horizontal defects

PANEL	P	FN	FP	N	Total
TV 58"	4	-	-	3	7
TV 55"	6	-	-	5	11
TV 48"	4	-	-	6	10
TV 46"	3	-	-	3	6
TV 42"	3	-	-	9	12

C. Strange body

Sometimes dust or other strange bodies may enter in the TFT-LCD plant, causing the defect shown in Figure 4, which, most of times, is not perceptible whenever the panel is not lit. The recognition results are presented in Table 3.

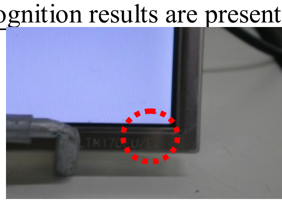

Fig. 4 – Detail of a lit panel with a strange body in.

Table 03 – Strange body detection results

PAINEL	P	FN	FP	N	Total
TV 58"	6	-	-	3	9
TV 55"	4	-	-	5	9
TV 48"	4	-	-	6	10
TV 46"	2	-	-	3	5
TV 42"	1	-	-	9	10

D. Stain image

Figure 5 shows a dark stain in a TFT-LCD panel. This is an irregular shape defect that is only noticeable with a lit panel and, as shown in Table 4, is the test that presents the highest number of false results.

Fig. 5 – Dark stain image.

Table 04 – Stain image detection

PAINEL	P	FN	FP	N	Total
TV 58"	6	3	1	5	15
TV 55"	2	1	3	5	10
TV 48"	4	2	2	6	14
TV 46"	3	1	2	7	13
TV 42"	6	1	1	3	11

E. Strange body in Red

Figure 6 shows a strange body in a panel presented in image.

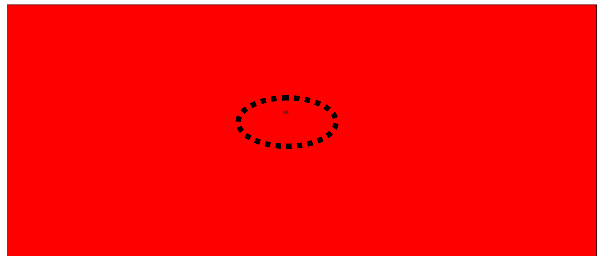

Fig. 6 – Strange body in Red image

The results obtained for the image defect shown in Figure 6 is presented in Table 05.

Table 05 – Strange body in Red image

PANEL	P	FN	FP	N	Total
TV 58"	11	-	-	5	16
TV 55"	9	-	-	8	17
TV 48"	4	-	-	4	8
TV 46"	5	-	-	8	13
TV 42"	2	-	-	3	5

F. Dark dot in Red

Figure 7 presents an example of a dark dot in red image. Notice that this sort of defect may be confused with the previous one, but its size and origin are different.

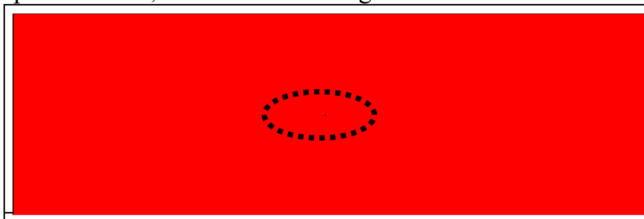

Fig. 7– Dark dot in Red image

The results obtained are presented in Table 06.

Table 06 – Dark dot in Red image

PANEL	P	FN	FP	N	Total
TV 58"	6	-	-	4	10
TV 55"	2	-	-	5	7
TV 48"	4	-	-	12	16
TV 46"	7	-	-	5	12
TV 42"	5	-	-	9	14

G. Abnormal image

Figure 8 presents an example of an abnormal image, which is easily detected as it affects the whole screen area. Table 07 provides the statistics of the results.

Fig. 8– Abnormal image

Table 07 – Abnormal image

PANEL	P	FN	FP	N	Total
TV 58''	7	-	-	4	11
TV 55''	4	-	-	5	9
TV 48''	3	-	-	12	15
TV 46''	2	-	-	5	7
TV 42''	6	-	-	9	15

H. Clear dot

Figure 9 presents an example of a clear dot defect in image.

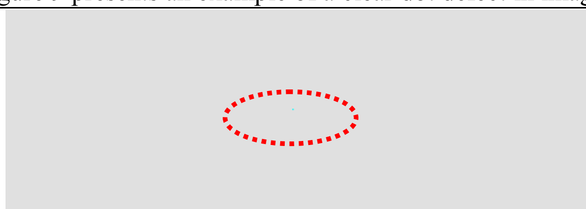

Fig. 8– Clear dot defect

Table 08 – Abnormal image

PANEL	P	FN	FP	N	Total
TV 58''	8	1	-	4	13
TV 55''	4	-	-	5	9
TV 48''	4	-	-	12	16
TV 46''	7	2	-	5	14
TV 42''	2	2	1	9	14

V. CONCLUSIONS

Quality control is a key factor for the reliability of products. The good reputation of a manufacturer within the consuming market is one of the most important patrimonies of a corporation. Samsung Corporation, besides offering to the market products that are in the frontier of the technology and design, it also focuses in quality and reliability, as fundamental features of each single produced item. TFT-LCD panels are widely used as display in a wide range of products. The number of defects in panels registered in the Samsung Manaus (Brazil) product line under human inspection during the burn-in phase during the whole year of 2014 was less than 2.2 x 10^{-4}. The number of defects reported by the technical assistance network during the guarantee period of the products manufactured in previous years was very low, thus the in-home quality inspection may be considered satisfactory. However, automatic inspection brings an even higher degree of reliability to such production phase and removes a large bottleneck in the manufacturing process.

The prototype platform outlined here has shown satisfactory results both in the number of defects spotted and processing times, in such a way that the possibility of being incorporated to the production flow of the assembly line is being considered. The authors are currently analyzing ways of reducing the number of False Positive results in the case of stain image detection, that reached 14% of the number of items checked. If the presented platform were incorporated to the product line, it is most probable that it will be made in parallel with the human one for a long period. In doing so, a far larger quantity of data will be obtained, allowing better training of the recognizer, possibly yielding even better detection performance.

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