COMPUTER VISUAL INSPECTION OF LIQUID CRYSTAL DISPLAYS

Sven J. Dickinson, Louis M. Gaiot, and Marvin E. Jernigan

Department of Systems Design
University of Waterloo
Waterloo, Ontario

Abstract

A computer vision system for the inspection of liquid crystal displays (LCDs) has been designed to provide consistent, efficient analysis of LCD quality. Two algorithms for inspection have been identified: a feature matching method which compares features based on adjacent pixel differences of a test LCD image with those features obtained from a reference image, and a decision theoretic approach which compares positional and shape characteristics of blobs in a test LCD image with those of a reference image. The former method can be implemented using hardware and is therefore very fast. However, this method suffers when images are misaligned and provides no error classification. The latter method is slower but more flexible and provides effective error classification.

1. INTRODUCTION

The manufacturing of liquid crystal displays (LCDs) is a complex procedure requiring precision glass cutting, exact etching processes, and perfect assembly. As a result, a variety of flaws can be introduced into the LCD. As diverse as these flaws are, however, they can all be characterized by either the absence of required polarized regions or the presence of extraneous polarized regions in the LCD.

As is common with all manufacturing processes, the LCDs proceed through rigorous inspection before shipment. At the present time, the majority of LCDs are inspected by humans. However, due to the range in both the size and characteristics of the flaws, it is very difficult to ensure a consistent, objective analysis of quality. Consequently, it is not uncommon to find three or four individuals, in turn, inspecting the LCDs. This process is time-consuming, inefficient, and inaccurate. Clearly, there is a need for an automated test procedure which can ensure consistent, accurate results while providing economic benefits.

This paper discusses a system designed at the University of Waterloo to provide automatic visual inspection of LCDs through the use of computer vision techniques. Two algorithms for LCD inspection are presented and analysed, followed by a discussion of practical considerations in setting up such a system.

II. LCD FLAWS

The two most common types of flaws occurring in an LCD are those caused by the misalignment of the upper glass (segment electrode) and the lower glass (common electrode), and by damaged electrodes. The former flaw gives rise to a truncated appearance in an LCD segment (Figure 1) while the latter gives rise to pattern defects (Figure 2). Less frequent errors result from trapped air between the two plates and from imperfections on the internal glass surfaces.

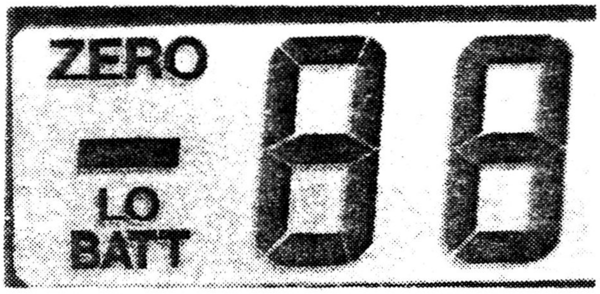


Figure 1. Alignment Error.

Figure 2. Pattern Defect.

III. SYSTEM ARCHITECTURE

For LCD inspection, the realization of an automated visual inspection system is accomplished using the system architecture shown in Figure 3. The digitizer would be of the "frame grabbing" type that will digitize an image in less than one second. The minimum required resolution is 256x256 pixels where each pixel is quantized using 8 bits. A host processing system using a high performance microprocessor such as the Motorola MC68000 would be required to perform all image processing operations. An 8-bit slave processor is used to perform input/output servicing and to control an x-y table upon which an LCD jig is mounted. Having a slave processor perform non-image processing related tasks allows the main processor to concentrate on image processing operations only. The display peripherals and keyboard provide the feedback and control mediums for the operator.

The prototype system assembled for algorithm development and evaluation consists of a Panasonic WB1500 B/W video camera and a Tecmar video digitizer. The resolution of the camera is 650 lines while the digitizer resolution is 256x256 pixels by 256 gray levels. The 64 Kbyte digital image is loaded directly into the on-board processing system memory. The time required to scan, digitize, and store an image is approx. 3-4 minutes. The processing system consists of an Intel 8088 based IBM PC with 256 Kbytes of RAM. The processor subsystem controls image digitization, performs all preprocessing functions, and executes the inspection algorithms. The display system consists of a TV video monitor to assist in camera calibration, lighting control, etc., and a graphics monitor to display digitized images and provide user feedback.

IV. IMAGE PREPROCESSING

Careful inspection of Figures 1 and 2 will reveal that the LCD background is composed of gray specks. As the sampling interval becomes small, the specks become discrete points and can be modelled as point-source noise. To reduce the effects of this condition, a median filter is applied to the image. Using the median filter, a pixel and its 8 immediate neighbours are ranked according to intensity value. The fifth (median) value is assigned to the centre pixel. This process is repeated for each pixel in the image. The median filter smooths out random pixel fluctuations while preserving edge sharpness. Thus, the effects of the speckled nature of the LCD background are minimized without degrading image quality.

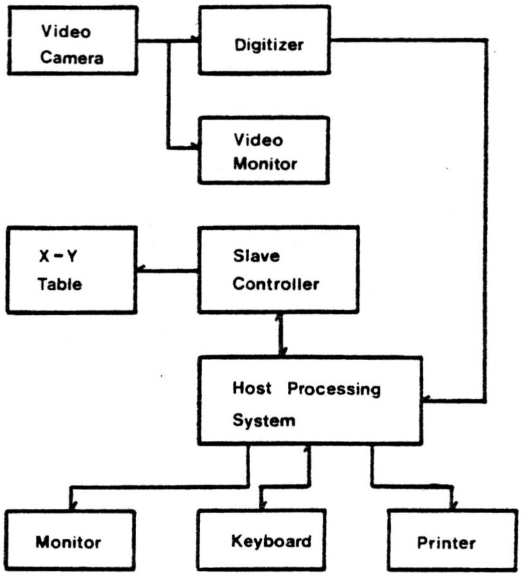


Figure 3. System Architecture.

V. METHODS OF INSPECTION

Two visual inspection algorithms were tested using the prototype system: a feature matching approach and a decision theoretic approach. Both methods require a priori knowledge of a flawless LCD and consist of both a training phase and a testing phase. A third method, image subtraction, was tested because of its speed and simplicity. However, this method was discarded due to its sensitivity to both environmental lighting conditions and alignment of the test and reference images.

Feature Matching

Chandra et al. [1] propose a feature matching method for image registration which is computationally more efficient than standard correlation algorithms. This technique involves representing the image by a feature vector based on adjacent pixel differences along the rows and columns of the digital image. Given P, an MxN matrix of pixels representing the prototype or reference image, and T, a KxL array of pixels representing the test image, the LCD integrity is determined by the similarity between the feature vectors of the two images. The (K+L)-dimensional feature vector, V_T, of the test image, T, is defined in equation (1) with its elements defined in equations (2) and (3), respectively.

$$V_T^T = [R_1, R_2 \dots R_K C_1 C_2 \dots C_L] \qquad (1)$$

$$R_K = \frac{\sum_{j=1}^{L-1} |T(k,j) - T(k,j+1)|}{\sum_{j=1}^{L} |T(k,j)|} \qquad (2)$$

$$C_\ell = \frac{\sum_{i=1}^{K-1} |T(i,\ell) - T(i+1,\ell)|}{\sum_{i=1}^{K} |T(i,\ell)|} \qquad (3)$$

Similar equations define the feature vector V_R, of the reference image.

The feature vector of the reference image is correlated with the feature vector of the test LCD image using the relation described in equation (4).

$$C = \frac{V_T^T \, V_R}{\|V_T\| \|V_R\|} \qquad (4)$$

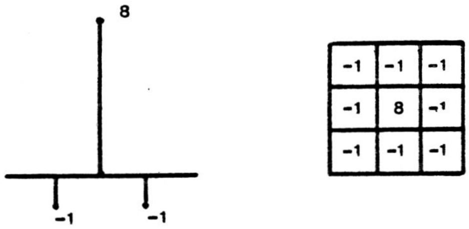
A threshold is defined for the resulting correlation beyond which the test LCD image is categorized as flawless and below which the LCD image is labelled as unacceptable.

When reference and test images are compared, the images are rarely aligned pixel for pixel. Although rotational alignment is ensured (for flawless LCDs), the test image may be displaced both vertically and horizontally relative to the reference image. When implementating the feature matching algorithm, the test image is shifted relative to the reference image. When the two images are properly aligned, the correlation of the two feature vectors will yield a maximum.

Decision Theoretic

In the decision theoretic approach, an LCD image is represented by a set of N extracted features based on shape characteristics of objects or blobs in the image. Any isolated dark region (e.g. letter or digit) in the image is considered a blob. The features of the test LCD image are compared to the features of the reference LCD image. The similarity of these feature vectors determines the integrity of the test LCD.

The first operation performed on the digitized LCD image is a global thresholding in order to create a binary image. A binary representation of the original image facilitates further image processing and eliminates the LCD background point-source noise. Next, the binary image is convolved with an edge detection operator of the form shown in Figure 4. The edge detection template has dimensions of 3x3. Since the operator has a zero DC gain, all regions of constant intensity will be mapped to zero. Only the edges between regions of different intensity will be emphasized.



-1	-1	-1
-1	8	-1
-1	-1	-1

Figure 4. Edge Detection Operator.

The features extracted from the edge image that provide the necessary positional information of a blob are as follows:

1) centroid of a segment, $(\bar{x},\bar{y})$ where [2]:

$$\bar{x} = m_{10}/m_{00}$$

$$\bar{y} = m_{01}/m_{00}$$

2) coordinates of the centre of an enclosing rectangle, (x_c, y_c)

The first three moments are found as follows:

$$m_{00} = \text{area} = P_1$$

$$m_{10} = P_2/2$$

$$m_{01} = P_3/2$$

The P_i terms are accumulated during the chain coding process for each blob according to the edge coding convention shown in Figure 5:

for boundary code = 0

$$x = x + 1$$

$$P_3 = P_3 - y^2$$

for boundary code = 1

$$y = y - 1$$

$$P_1 = P_1 - x$$

$$P_2 = P_2 - x^2$$

for boundary code = 2

$$x = x - 1$$

$$P_3 = P_3 + y^3$$

for boundary code = 3

$$y = y + 1$$

$$P_1 = P_1 + x$$

$$P_2 = P_2 + x^2$$

The extracted features obtained during the edge coding process that provide shape information of the blob are as follows:

1) segment perimeter length
2) coordinates of the corners of an enclosing rectangle
3) segment area
4) encoded sequence of segment perimeter
5) number of ones along the verticle axis through the center of an enclosing rectangle.

In this implementation, the edge image is used for blob edge encoding. The image data is scanned in a raster-like fashion until an edge pixel is encountered. The pixel coordinates for the first edge point are stored in memory and the scanning process is aborted for the duration of the edge encoding process. From the first edge pixel of the blob, the program follows the blob edge creating a sequence of direction numbers describing the edge orientation at each edge pixel. Using the coding convention shown in Figure 5, a sample edge coding procedure is illustrated in Figure 6. Once the entire edge is encoded, the edge is deleted from the image and the scan re-initiated from the last aborted scan position.

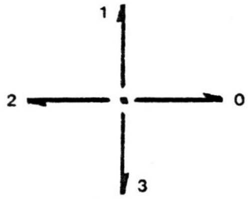


Figure 5. Edge Coding Convention.

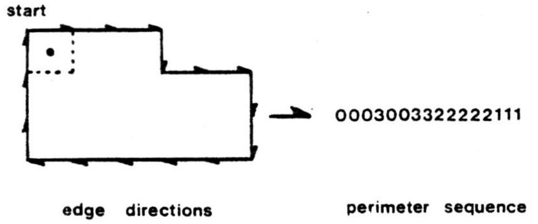


Figure 7. Edge Coding Procedure for a Sample Blob.

Since the blob features extracted describe the important shape properties of an LCD blob, it is possible to categorize the type of flaw that may exist in the blob. The blob perimeter, the dimensions of the enclosing rectangle, and an examination of the edge code sequence are used to identify pattern defects (Figure 2). The above features plus area help to spot gross LCD blob defects and the total number of blobs encountered in a sample is checked for missing or extra blobs. These extra or missing blobs are found by comparing the centroids of sample LCD blobs to those of the reference blobs. Misalignment problems (Figure 1) are detected by comparing the cross-sectional information, areas, and perimeters.

VI. RESULTS

The feature matching inspection method performs consistently well with both alignment and pattern defect errors. However, an extensive calibration procedure is required to determine a consistent correlation tolerance for acceptable LCDs given the ambient lighting conditions. In addition, the correlation tolerance is very sensitive to the size of the flaws. The camera magnification, therefore, must be calibrated according to the size of the smallest anticipated flaw.

The feature matching method can calculate the feature vector of a 256x256 image in approx. 30 seconds. When the test and reference images are nearly aligned, few iterations are required to superimpose the two images and achieve maximum correlation. However, as relative displacement between the two images becomes large, inspection time increases at a rate proportional to the amount of misalignment.

The decision theoretic approach also performed well and identified a greater margin between acceptable and non-acceptable LCDs. Precise alignment of reference and test images was unnecessary with misalignment causing no appreciable increase in execution time.

The decision theoretic approach generally requires more execution time than the feature matching technique. Whereas the feature matching technique execution time is independent of image content, the execution time for the decision theoretic approach varies with the number and size of the blobs in the image.

The decision theoretic approach has the capability to identify the types of errors encountered and performed well under test. Errors insensitive to one feature were sensitive to at least one other feature.

VII. CONCLUSIONS

There is a definite need for an automated LCD inspection system that can provide consistent evaluation of LCDs plagued with a variety of flaws. Of the algorithms tested for LCD inspection, a combination of the feature matching method and the decision theoretic approach will provide a system with both speed and flexibility. The feature matching method can be easily implemented in hardware [1] and would be a valuable addition to the set of features defined by the decision theoretic approach.

The success of such a computer vision inspection system depends heavily upon the control of environmental lighting conditions and camera isolation. Although the LCDs do not require special illumination for testing, illumination must remain constant throughout testing. A bright diffuse lighting environment results in cleaner image acquisition.

In implementing a system able to handle varying sizes of LCDs, a method for image registration must be used to combine multiple images into a composite image. In this case, the feature matching method is ideal for aligning the borders of overlapping images. To minimize overlap, an X-Y table can be used to position the LCD under the camera with a high degree of accuracy.

The prototype system was clearly inadequate for this application in terms of computing speed. A 32-bit architecture would be vastly superior both in memory size and processor speed. The digitizer must be effectively instantaneous in sampling an image and should not contribute significantly to the overall inspection time.

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