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Automatic Vision System for Finall Test of Liquid Crystal Displays

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Abstract

This paper describes algorithms and hardware of the automatic output check system for liquid crystal displays (LCD). A new TV camera and high speed video processor of data flow architecture are presented. The main algorithmic difficulty of LCD check problem is detection of little defects in real time. To do this, the algorithm utilizing a priori information was designed. The methods used for functional LCD check do not require any human interference for its accommodation to new LCD types.

1 Introduction

One of the few manual operations in the almost fully automatic manufacturing of liquid crystal displays (LCD) is visual output check. This fact, combined with the need of multifold increase of production makes the task of visual check automation currently central.

The LCD output check is subdivided into the appearance and function checking.

The following defects at the operating field of LCD surface must be found during the appearance check: nap, hairs, splits, bubbles, dark spots and other flaws larger than those of allowable size.

LCD function check tests are the following: lighting up and proper shape of all display segments, absence of short circuits between segments, value of current power consumption, quench and switch-on times.

The vision system (VS), that implements check operations must work in real time. The term "work in real time" means here the time restrictions on image input, processing and making decision for the analyzed scene. In this LCD check system it is the time required to prepare the robot for a next LCD positioning, which is equal to 5 s.

Moreover, the system must be flexible (easy resetting to another LCD type) and highly reliable, i.e. provide check with efficiency not less than in manual checking.

Two stages may be singled out in the development of the vision system for automatic output check of LCD.

At the first stage a high-speed half-tone sensor OT-10MT was used [1, 2] as the hardware means. This sensor was employed to assign numerical values to images of 256x256 pixels in size with quantization of luminosity into 16 levels. These images were sent fragment by fragment into the 4K buffer memory.

At this stage the functional real-time check was implemented and the software for automatic appearance check was developed [3, 4].

Using modified hardware means based on the concept of a special modular data flow videoprocessor [5, 6, 7] the problem of automatic output real-time check was solved completely. This modified system is described below.

2 Hardware

The LCD automatic check system is a flexible unit that includes a visual system, a special processor for effectors operation, two air-driven robot loaders, two drum storage devices (input-output) for storing cassettes with LCD, destination cassettes for faulty LCD, a device for precise positioning before visual check, a contact device of control position, a device for measuring LCD electric parameters, a work table connecting all components in a single unit.

To be able to detect defects that become visible at a certain visual angle to LCD the unit includes a device for operating the LCD illumination directions (uniform, from left, from right, from above and from below).

3 Vision system

The vision system used for automatic LCD check has the following configuration:

- TV camera, based on deflectron;
- special data flow video processor (SVP);
- one-board microcomputer;
- video monitor.

The deflectron-based TV camera (improved vidicon) was chosen according to its following description: high resolution (1600 lines at the center, 1200 on edges), small geometrical distortions (0,2 %), high image stability (displacements within one pixel).

The special video processor has a modular structure(fig. 1). The information exchange between modules is made through high speed flow interfaces. This permits relieving the system bus and significantly raising the exchange rate. So the maximum exchange rate

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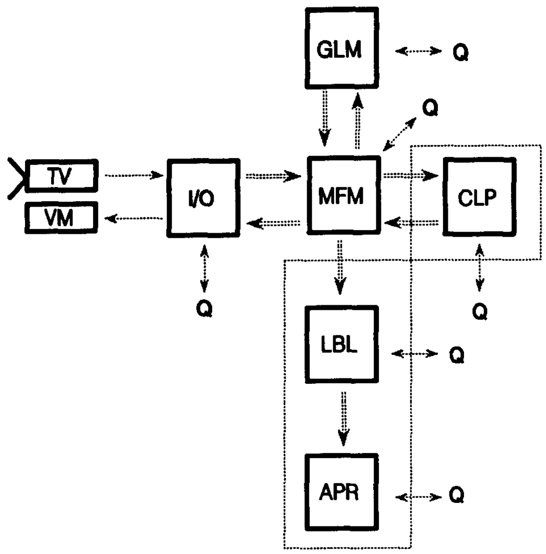


Figure 1: Architecture of the special video processor. Denotations: TV — TV camera; VM — video monitor; double arrows — data flows; dotted arrows — analog video dates; single arrows — system bus links; I/O — input/output module; MFM — multifunctional module; GLM — gray level memory module; CLP — "cell logic processor" module; LBL — "Label" module; APR — "Arithmetical processor" module; dotted rectangles — optional elements.

on Q-bus is equal to 2 Mbyte/s, while exchange rate on flow interface mounts up to 16 Mbyte/s.

These are the following basic features of SVP:

- the input of frame at a rate of television scanning (the raster is 512 x 512 pixel and number of gray levels is equal to 64);
- the histogram calculation and look-up table transformation as well as binarization of any rectangular image fragment at a rate of 16 Mbyte/s;
- the processing of cell logic operations controlled by built-in microcomputer at a rate of 32 million eight- neighborhood operations per second (a convolution of the whole bilevel image with user-defined 3 x 3 mask);
- the extraction up to 14 thousand connected components on bilevel image with calculation of its characteristics (the area, coordinate limits, second order moments and the like).

4 Algorithms of appearance check

In terms of image analysis, the detection of appearance defects is a task of (1) calculating areas of connected contrast objects, different in brightness comparing to the basic background, and (2) decision making about fault or fitness of LCD by basing on the distribution of areas.

The connected regions extraction algorithm which faces grave computational difficulties since it requires about 1 million operations on a common computer, is implemented in SVP.

The greatest difficulty is gray level image binarization of the faulty LCD, i.e. conversion to bilevel image, where 0 corresponds to fitness surface and 1 corresponds to defect. This difficulty is caused by insufficient uniformity of field of vision illumination and brightness distortions in system video channel. These factors do not allow using a single threshold of binarization for the whole image. The common approach to solving this problem is preliminary low pass image filtration. But this operation is too slow even if the hardware support (available for the authors) is used.

This predicament may be overcome by using a priori information. We used the knowledge about the brightness distribution of standard LCD image as such a priori information. The representation form of this distribution is "illumination pattern", which includes a list of quasi-constant brightness zones and a set of ranges of allowed brightness for each zone.

A quasi-constant brightness zone is defined as a image region where brightness irregularity caused by illumination is not greater than the specified threshold.

To increase the stability against a total proportional change of brightness, described by the following formula:

$$B' = kB \qquad (1)$$

the brightness ranges $[B_{min}; B_{max}]$ from the "illumination pattern" are reduced to $[\tilde{B}_{min}; \tilde{B}_{max}]$ form, where $\tilde{B} = B/\bar{M}$, $\bar{M}$ — is average brightness of the background. Here and below B and B with indices mark different values of illumination or luminosity explained in the text.

To understand used algorithms it is necessary to answer two questions: "How are quasi-constant brightness zones chosen?" and "How is the average brightness of background $\bar{M}$ calculated?".

Let us first consider the question of calculating the average brightness of background $\bar{M}$, based on the histogram of brightness distribution G : B → N, where $G(B)$ is the number of pixels, the brightness of which is equal to B. The most difficult task is the $\bar{M}$ calculation on the image of fully switched-on LCD. Such a situation arises during checking operation of segment shapes. The typical histogram in this case takes the form of two pronounced peaks with the gap between them (fig. 2).

The right peak (greater brightness) corresponds to the light background, the left corresponds to the dark display segments or dark spots. The case of a large light spot is regarded unlikely and not considered.

The algorithm suggests to compute $\bar{M}$ only from pixels, the brightness of which is close to supposed brightness of background (the region between B_0 and B_1 in fig. 2). As a result, the effect of non-background pixels upon the $\bar{M}$ value is essentially decreased. Since the background is known to be lighter than segments, the point of absolute maximum in the right half-histogram B_{peak} is chosen as the supposed background

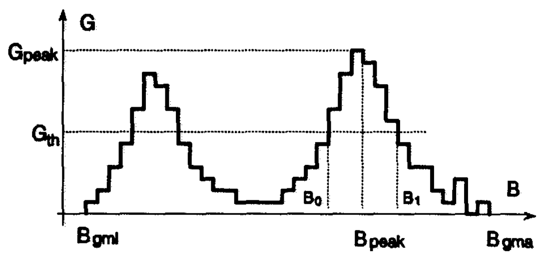


Figure 2: Calculation of average background brightness.

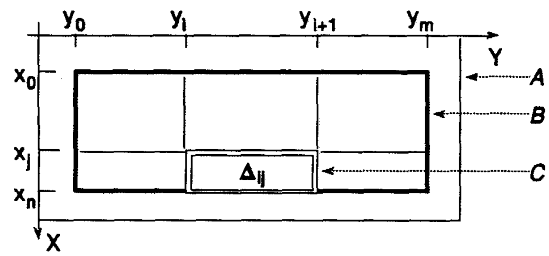


Figure 3: Fragmentation of field of vision into quasi-constant brightness zones Δ_{ij}. Denotations: A — eyesight, B — work space, C — splitting element

brightness. $\bar{M}$ is next made more precise by averaging of the histogram in the range from B_0 to B_1 calculation.

$$G_{peak} = \max(G(B)) \text{ , while } B \in [(B_{gmin} + B_{gmax})/2; B_{gmax}] \quad (2)$$

$$G_{th} = G_{peak} K_{th} \quad (3)$$

$$B_{peak} = \arg(G_{peak}) \quad (4)$$

K_{th} is defined experimentally. B_0 and B_1 are closest to B_{peak} (left and right respectively) brightness that $G(B_0 - 1) < G_{th}$ and $G(B_1 + 1) < G_{th}$.

$$\bar{M} = \sum_{B=B_0}^{B_1} BG(B) \;\; / \sum_{B=B_0}^{B_1} G(B) \quad (5)$$

Let us consider the algorithm for computing the quasi- constant brightness zones. The condition that the brightness irregularity in every zone Δ_{ij} is greater than the specified threshold ϵ can be written as follows:

$$\forall i, j \left\{ \max_{\Delta_{ij}} B - \min_{\Delta_{ij}} B \right\} \leq \epsilon. \quad (6)$$

For simplifying the program implementation, the fragmentation of rectangular field of vision

$$\{x, y | x_0 \leq x \leq x_m, y_0 \leq y \leq y_m\}$$

is sought among fragmentations of the following kind:

$$\{\Delta_{ij}\} = \{\Delta_i^X\} \times \{\Delta_j^Y\} \text{ , where}$$

$\{\Delta_i^X\}$ and $\{\Delta_j^Y\}$ are fragmentations of intervals $[x_0; x_m]$ and $[y_0; y_m]$ respectively (fig. 3).

The fragmentation procedure is the iterative process with initial conditions

$$\{\Delta_i^X\} = \{[x_0; x_m]\} \qquad \{\Delta_j^Y\} = \{[y_0; y_m]\} \quad (7)$$

and the termination criterion 6.

In this way the algorithm of image transformation to bilevel form (background/defect) may be reduced to simple thresholds in each zone to be chosen during the learning process. The threshold values in each zone are functions of boundaries of permitted brightness range calculated during the learning process and an average background brightness, which is easily calculated by using hardware computed histogram of gray level distribution in this zone.

There is another problem caused by the fact that the system operates at the limit of its resolution (the linear size of image of defects measured by 1–2 pixels) — the problem of defect and noise separation in the binary image (the task named "salt and pepper" [8]).

However, the pixels that belong to defects must appear in the same place on repeated input images due to high TV raster stability. This fact allows the noise suppression by logical AND operation applied to two sequential binary images.

Notice that in the suggested algorithm the operations of image input, histogram calculation, binarization, binary image logical multiplication, labeling of connected components and their areas evaluation are performed by the SVP hardware. The central computer only manages the SVP, calculates thresholds on the histogram and makes decisions about faults. Distributing the roles between the software and hardware in such a way to implement the algorithm for appearance check we could carry out a required analysis in real time.

5 Algorithms for function check

From the above tasks of functional test let us dwell on two most typical characteristic items: check of segment breaks and short circuit between segments.

In checking the segment breaks it is necessary to test the presence and the shape of LCD segments. Taking advantage of binarization algorithm developed for the appearance check this test has been reduced to binary images analysis. Due to high TV raster stability and precision of manipulators that are used for the next LCD positioning the task was reduced to binary pattern matching.

During the preliminary system learning two binary images are formed (fig. 4).

These images split the field of vision into 3 regions: points that always appertain to the right side of display image (background region), points that always appertain to the segments image (object region) and

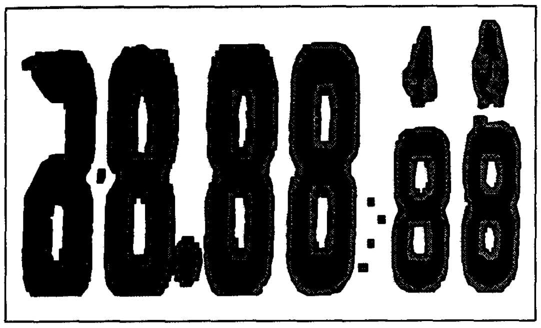


Figure 4: Pattern for test of segments break.

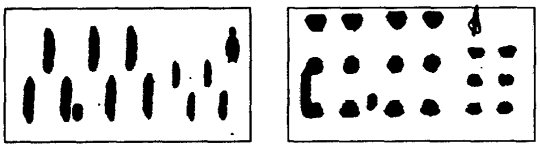


Figure 5: Test combination for circuit check.

points that may fall alternately in the background or object regions (boundary region). During the cycle of checking, binarized image is matched to patterns that have been formed by applying logical operations.

The glue layer on the display side has a variable width for a particular LCD. As a result, the LCD positioning error of ± 5 pixel exists. For its compensation the pattern is consequently matched with a tested binary image shifted by 0, 2, 4, 6, −2, −4, −6 pixels. The shift is implemented by the cell logic processor.

In general, all the mentioned operations (the information accumulation about standard display and pattern forming; input, thresholding and shifts of tested image; matching with pattern and defect areas calculations) are hardware implemented in SVP.

During the circuit check the LCD is energized for lighting up one or other test combination of segments (fig. 5). The objective of the system is to check the absence of segments that do not belong to it. This task is solved by analysis of known regions in binary image. Of some interest is an algorithm of automatic choice of these regions during the learning process. It consists of the following steps.

1. The difference images I_1 and I_2 ("not lighted up segments images") are formed first by basing on the pattern of segments break and binary image of standard combination (fig. 6).

2. Logical operations for merged segments separation are applied next to $I_1$and I_2 images (fig. 7).

3. The resulting images I_1^1 and I_2^1 are filtered for small objects erasing, holes filling and shrinking [9] to "root" points. Finally the test regions are built around computed "root" points of not lighted up segments (fig. 8).

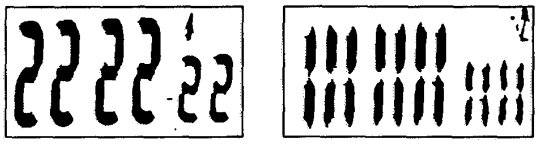
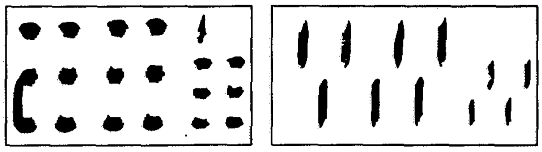


Figure 6: The difference images I_1 and I_2.



a *b*

Figure 7: A — $I_1^1 = I_1$ AND (NOT I_2), B - - $I_2^1 = I_1$ AND I_2.

Thus, the preliminary learning process is completely automated and does not require special knowledge from users.

6 Experimental results

In the experiments which were conduct by authors the value of $k_{th} = 0.5$ proved to be more acceptable. This value of the coefficient provide a reliable transition to a binary image.

On the basis of experiments with described automatic vision system for LCD final check the following results were obtained.

The automatic check time of one display is 5 s (compared to 30 s in manual check), including the appearance check time 1.5 s.

In this case appearance defects with contrast at least 0.2 and size of 4 to 5 pixels and with contrast at least 0.8 and size of 1 to 2 pixels.

The reliability of automatic vision check operations is 1–2 % of missed defects in appearance check and less than 1% in functional check.

The time of preliminary learning process for a new LCD type is not greater than 4 minutes.

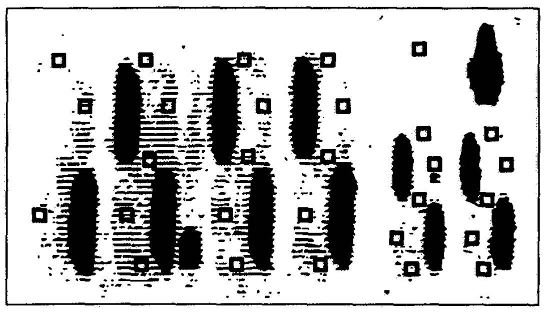


Figure 8: Test regions for circuit check.

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