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Automatic Adjustment of Television Sets Using an Uncalibrated Camera with a Novel Fuzzy Test Pattern and an Adaptive Alignment Algorithm

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Abstract: In this study we present the results of experimental research on an automatic adjustment system for television sets that relies on an inexpensive, uncalibrated camera to measure the geometric attributes of the TV screen and by using a closed-loop structure, sends adjustment signals which are generated by a computer to the television's internal EEPROM. Also several image processing tools have been utilized to measure the geometric parameters of the TV screen through the output images obtained by the camera. Control strategies are used to adjust and stabilize these parameters. We have already proposed and published a novel fuzzy test pattern and an adaptive alignment algorithm which are both used in the present research. This approach is implemented in real-time in a manufacturing house.

Key words: Automatic adjustment, geometric parameters, TV auto alignment, fuzzy pattern, adaptive alignment

INTRODUCTION

The geometric characteristics of a TV set can be only measured and adjusted by using a visual closed-loop control structure. We propose to automate this procedure in the production line at the manufacturing plants. Traditional methods used employ an expert human operator for tuning the geometric parameters of the television set. Naturally this is both time consuming and cannot be performed in real-time. We have already proposed and published a novel fuzzy test pattern (Toosizadeh and Peiravi, 2005) and an adaptive alignment algorithm for the displays (Peiravi and Toosizadeh, 2008) which we have used in this research and have implemented the present system in real time.

Advances made in the technology behind the manufacturing of television sets have made it possible to change the screen characteristics by modifying some digital values instead of tuning a few potentiometers. These digital values are stored in an EEPROM and can be changed simply by a service remote controller or the internal serial bus of the television set that is referred to as the I^2C Bus (Lindahl *et al*., 1994). Some of the advantages of this new technology are as follows:

- Reducing the number of assembling components to be assembled resulting in an increased reliability for the overall system
- Reducing the time needed to perform adjustments of the screen parameters
- Enhancing the quality of the television display

Therefore, these factors increase the production efficiency and reduce the overall cost of television manufacturing. A description on how this digital technology works internally in television sets and the definitions of some of the geometric parameters has been presented by Suckle (1988).

The geometric adjustment of a CRT display is usually done in two steps. In the first step that is known as the Integrated Tube Component (ITC) process, an operator has to adjust the colour purity rings and deflection yokes on the CRT. In the second step, an operator has to adjust the display circuitry using various potentiometers on the display's circuit board (Yerem, 2001). In this study we consider the second step for adjustment of the geometric parameters of the television set. The adjustment of geometric parameters by human operators seems to be an easy task. However, it is a very tedious task if it should be performed continuously over time. In addition, constantly looking at a television screen from a short distance is very harmful for the human eyes. Moreover, a few of the screen parameters cannot be accurately adjusted by a human operator and such adjustments are highly dependent on the operator's experience and personal judgment (e.g., S-Correction which is vertical linearity and RGB parameters). Continuous exposure to the X-rays produced in the vicinity of the CRT is also very dangerous for the human operators.

In this study, we present a novel approach for the automation of this calibration procedure in order to increase the accuracy and the uniformity of the adjustment of the parameters. We shall refer to this

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automation system as the auto-alignment system. Such an automation can increase the rate of production and the quality of the displays coming out of a television manufacturing factory. A discussion about the image quality model and the concept of the Image Quality Circle (IQC) has been represented by Engeldrum (1999). An auto-alignment system can be used to apply objective image quality and subjective image quality (Engeldrum, 1999) to adjust physical image parameters of the television set.

Earlier study carried out in order to simplify and automate the adjustment of the geometric characteristics of the CRT display are as follows: 2D and 3D models of the CRT have been used in systems presented by Webb *et al.* (1993) and Webb and Kern (1996) for transforming coordinate systems in an automated video monitor alignment system. These systems need the CRT model and a high-precision assembly line conveyor system with low tolerance fixturing. In another patented study, an inspection system that uses multiple high-resolution inspection cameras, in conjunction with a single stereoscopic reference camera have been introduced by Fridge (1997). A more recent work on the ITC measurement of the CRT display has been proposed by Chuang *et al.* (1999). A method for adjusting image geometry in video display monitor by the use of a human operator feedback through an input device has been patented by Devine (1999). A complicated system with multiple cameras and photodiodes for testing and aligning a CRT which can perform a series of required tests has been presented by Buckley *et al.* (1999, 2001). Even more recently, Webb and Simpson (2001, 2002) patented an apparatus and a method by using a host computer processor and the memory associated with the video graphics controller to dynamically adjust video images on the CRT screen in order to reduce the costs of CRT monitors manufacturing without the limitation on dynamic alignment techniques.

All of the aforementioned systems have complexities such as the need to use multiple cameras or one camera with a fixture and some predefined information such as 3D model of the CRT. Therefore, they are computationally intensive. We have presented a novel approach to reduce these complexities.

THE PROPOSED SCHEME

In this study we present the results of the implementation of a machine-vision based control system by an image-based structure (Hutchinson *et al.*, 1996; Shen, 2000) through relative measurements that require no camera calibration. This visual control system can be used as an auto-alignment system for television sets (Fig. 1). Here, we will discuss the construction of the present novel auto-alignment system for the television.

In this system the pattern generator generates a suitable pattern on the TV screen to measure each geometric attribute. A vision system placed in the feedback loop transfers the images of the TV screen through a frame grabber. This is input to a measuring algorithm to gauge the geometric characteristics of the television screen being adjusted. A digital controller compares the measured values with corresponding set points to form the control signal that is used as an appropriate adjustment signal. This process is repeated over and over until the error between the measured and the desired values becomes less than a predefined tolerable value.

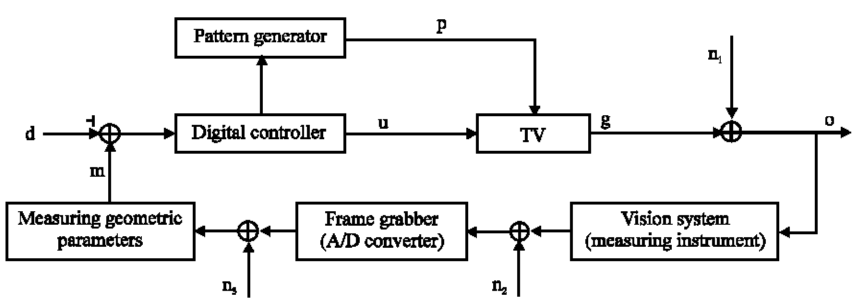

Fig. 1: Block diagram of the closed-loop system to automate the alignment of TV screen, d: Set points of the geometric parameters of the TV screen, m: Measured values of geometric parameters of the TV screen, u: Control signal to adjust parameters, g: Visual geometric characteristics of the TV screen, p: Generated pattern to measure TV screen attribute, n_1: Ambient light noise, n_2: CCD noise, lens disturbance, CCD resolution and so on and n_3: Analog to digital converter noise

SYSTEM DESCRIPTION

Our television auto-alignment system contains a Panasonic colour video camera of 768×576 resolution and a 450 MHz AMD-K6II PC with two display graphics cards, one used as a pattern generator and the other one used as a user interface. Also, a Pinnacle PC-TV video capture card with the maximum resolution of 768×576 has been installed in the PC as a frame grabber. The PC produces a suitable pattern on the television screen being adjusted through the specified graphics card and then the video camera transfers the image of the television screen through the frame grabber to the measurement algorithm that runs on the PC. The pattern used and the adjustment parameters are properly considered in the measurement algorithm. The digital controller that is also running on the PC uses the measured values and respective set points to generate the adjustment control signal. An infrared transmitter that has been connected to the PC's parallel port sends the specified adjustment signal to the television being adjusted. This adjustment process is repeated over and over until a tolerable adjustment of the geometric characteristics is achieved. This process of repeated operations usually takes around four iterations to be completed that is around 90 sec on our platform.

DIFFICULTIES IN SYSTEM DESIGN

Some of the difficulties that we encountered in the design of the proposed automatic adjustment system for the geometric parameters of a CRT are as follow:

- The mutual effect of some of the geometric characteristics yields a multi-input multi-output plant that is difficult to control
- The non-linear relationship between the input signals and the measured outputs that represent the geometric characteristics of the CRT due to the screen not being flat
- The existence of noise due to ambient light, noise of the camera's CCD, the noise in the video capture card, etc. introduce difficulties in the measurement process
- The possible variations of the relative pose between the camera and the CRT with the actual attributes of the camera lens (Motai Kosaka, 2001) introduce some distortions in the closed loop control system

In addition, the synchronization of the camera frames by the frames of the television being adjusted must be considered. An auto alignment system must be capable of adjusting the geometric attributes of the CRT screen with a high degree of accuracy at a very short time. This places stringent requirements on processing time and demands the development and application of real-time algorithms to produce control signals.

THE DEFINITION OF ADJUSTMENT PARAMETERS

A critical issue in the design of an auto-alignment system is to define a suitable set of adjustment parameters based on the geometric characteristics of the television screen. Suppose that the geometric parameters of the television screen form a space such that each dimension in this space corresponds to one of the geometric parameters. The selection of the adjustment parameters must be such that they are fairly insensitive to the variation of television-camera pose and establish a unique point in the geometric parameters space of the television screen. In other words, there must be a one-to-one correspondence between the adjustment parameters and the geometric parameters of the television screen.

The present characteristics of the television production line in the manufacturing house are such that if we use a single fixed camera the variations of the television-camera pose are only possible in the horizontal direction. Any variations in the vertical direction would be minimal and can be ignored. The major types of variations in the television-camera pose consist of angular variations, depth variations and horizontal displacement as shown in Fig. 2.

Moreover, the definition of the adjustment parameters and the design of adjustment algorithm must be robust to displacement disturbances. Given the fact that in consecutive adjustments of the televisions running down the production line, the relative position of the camera with respect to the television set is variable, we decided to use an image-based control approach and selected the adjustment parameters proportional to the measured size of the TV screen being adjusted.

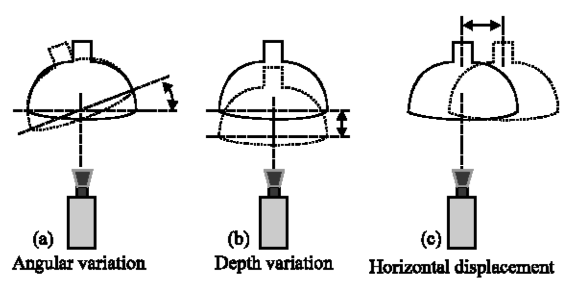

Fig. 2: All kinds of pose variations between a fixed camera and television on production line

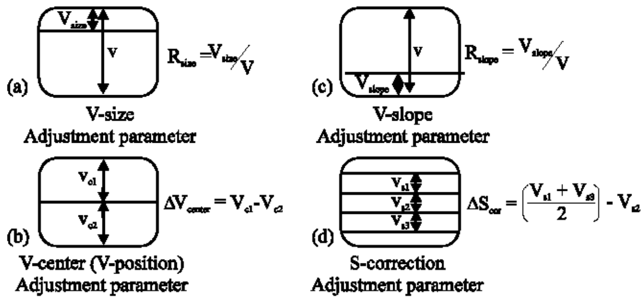

Fig. 3: Some vertical adjustment parameters actually used in present system

Definitions of several typical vertical parameters and the corresponding generated patterns on the TV screen are shown in Fig. 3.

It is clear that the displacement errors do not considerably affect the defined adjustment parameters. Note that the defined parameters are only related to the vertical geometric characteristics of the screen. Since the number of horizontal geometric parameters in television is usually more limited than the vertical ones, a similar but smaller set of parameters can also be considered for the horizontal direction. The defined adjustment parameters are related to the size and the relative location of the television screen being adjusted. Therefore, we need to develop an algorithm to detect the television screen in the captured image.

MEASUREMENT ALGORITHMS

Assuming that the relative camera-television pose is fixed during the adjustment of a given television set, we need to measure the precise location and the exact dimensions of the television screen in the captured image. This is obviously a critical factor in the estimation of the defined adjustment parameters. In order to achieve this, we brighten all the points of the television CRT screen by applying a white pattern first. The brightness of the television screen area is thus clearly separated from the surrounding area and can be used in the following captured images by applying an appropriate threshold to create suitable binary images. The next step would be to identify the screen boundary and eliminate the parasitic information outside the edges of the screen in the captured images. To achieve this we have developed a novel fast algorithm using a weighted window to follow the edge of the screen in the binary image.

Edge following algorithm: Present edge detection algorithm employs a weighted 3×3 window whose variants are shown in Fig. 4. On the figure each template relates to a case of the boundary pixels of convex shapes and its assigned value is unique. Of the templates shown, only template 15 does not relate to the boundary. It is related to the inside of the shape. For concave shapes, other templates must be added.

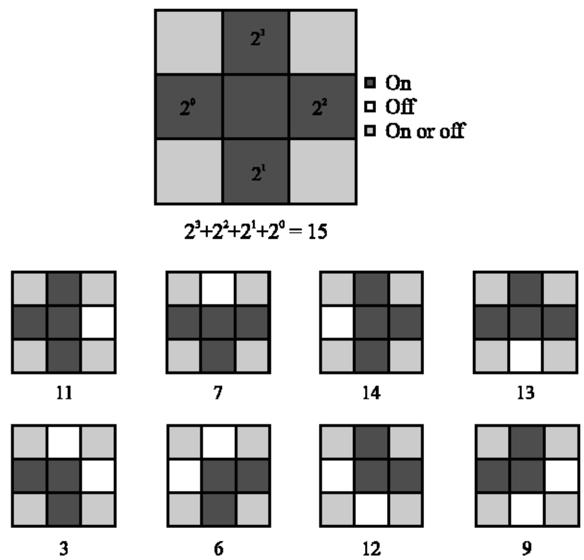

Fig. 4: Weighted 3×3 window and its significant variants

The value assigned to each template is simply calculated as follows: four of the pixels are assigned weights of 2^n as indicated in Fig. 4. If the corresponding pixels are on, the associated weights are counted. The sum of the weighted numbers related to the pixels in the window is computed in each location that the window is placed. The template matches and their corresponding location on the image of the CRT screen are shown in Fig. 5.

If we place the central point of the above window on any inner point of the screen boundary, a template match 15 occurs. Now if we move the window in any direction and proceed so far that we cross the boundary, a template match different from 15 occurs. In this situation, the central point of the window represents an edge pixel. After finding an edge point, we move the window in either

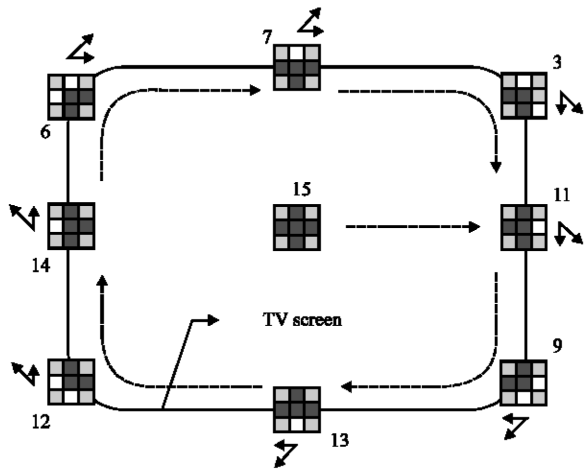

Fig. 5: TV screen and the detail of present edge following algorithm. Expected template matches are shown in the various locations

clockwise or counterclockwise direction on the screen boundary in an attempt to follow the edge of the CRT's image on the screen. We continue this procedure until the first edge point is encountered again. In this manner, all the edge pixels are found and are stored in another image in memory.

To illustrate how the edge of the CRT's image on the screen is followed in present algorithm, suppose we have an image of the TV screen as shown in Fig. 5. The original window placed inside the boundary of the screen is moved horizontally to the right until a template match other than 15 occurs. If the template match is 3, then we have reached the upper right corner; if it is 11, then we have reached the right side and if it is 9, we have reaced the lower right corner of the CRT's image on the screen.

Assume, for example, that we have encountered a template match 11 which indicates that we have reached the right side of the image. To follow the edge of the screen, we move the window down by one pixel. Before

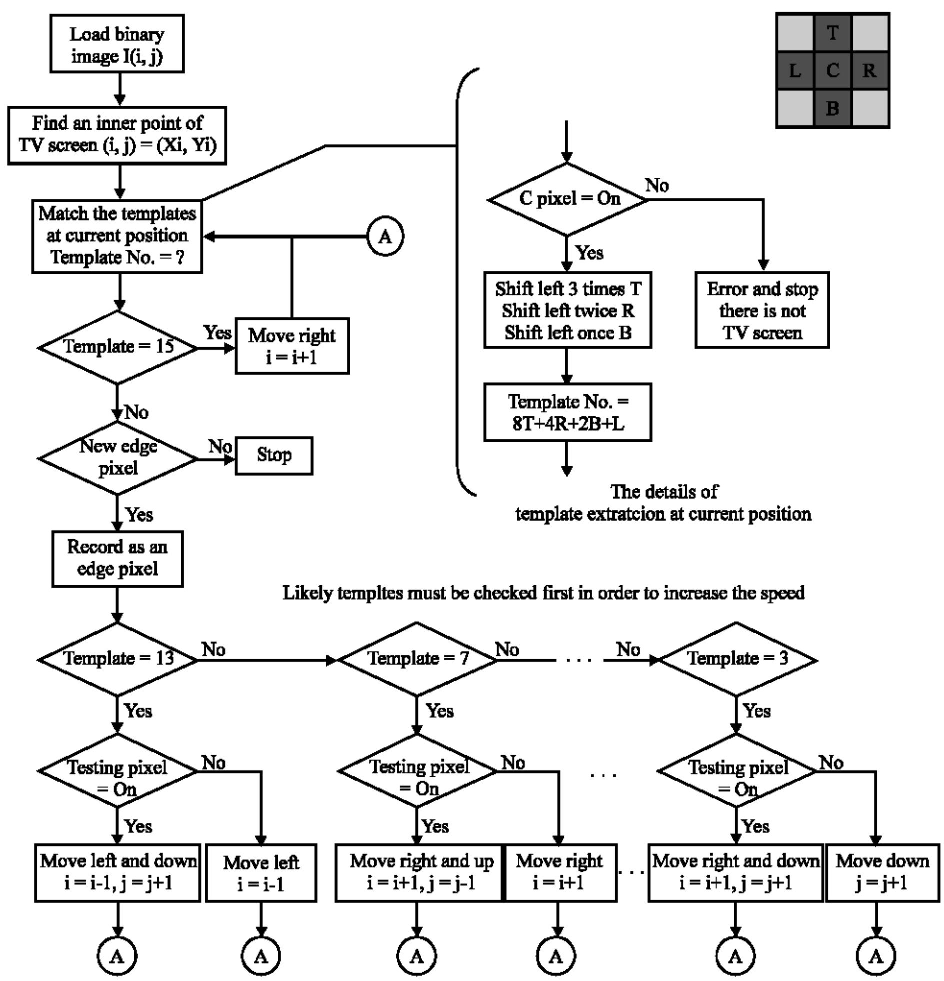

Fig. 6: Flowchart of the edge following algorithm

making this move, the right pixel in the bottom of the window is tested to see if it is located on the image of the screen. If it is, the window's center is placed on it as we move downwards. Otherwise the window is moved straight downwards. This process is continued until a template match other than 11 occurs. In this case it must be 9 indicating that we have reached the lower right corner of the CRT's image on the screen. Now before we move the window towards the left, we must test the lower left pixel of the window to see if it is located on the image of the screen or not. If it is, we move the window such that its center is located on that pixel. Otherwise, the window is moved straight to the left by one pixel. This process is continued in a similar manner until we reach the lower left corner. Then we move upwards to reach the upper left corner. Then we move to the right until we reach the upper right corner. Then we move downwards until we reach the boundary point at which we started our movement on the boundary. Obviously the template matches that occur as we reach the various corners-the right side, the left side, the bottom and the top of the screen-are all different from each other as indicated in Fig. 4 and 5. The flowchart of this algorithm is represented in Fig. 6. In order to save CPU time, we only use the basic shift operation rather than the computationally intensive multiplication operation in the computation of the weights for the window as depicted in the upper right corner of Fig. 6.

We compared the performance of present algorithm with that of Sobel's edge detection algorithm (Parker, 1997) since other edge detection algorithms are more difficult to code and much slower than Sobel's algorithm.

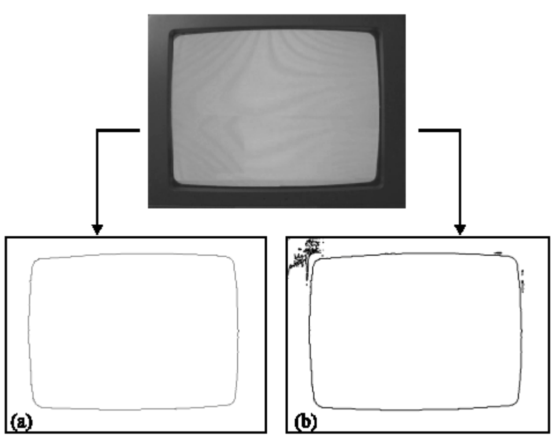

Fig. 7: Results of applying present proposed edge following and Sobel edge detection algorithms

The results are shown in Fig. 7 where, we can see the advantages of present proposed edge following algorithm in rejecting noise of ambient light on the front panel of the television. The speed of our algorithm to follow the edge of the TV screen in captured images is approximately nine times the speed of the Sobel edge detection algorithm. Both algorithms were efficiently programmed in C++ and were run on the same platform to make this comparison.

Another advantage of present suggested algorithm is that it can be used to quickly measure the dimensions of the TV screen, whereas existing algorithms lack this potential.

Detecting the screen's border: During the detection of the screen's border, the coordinates of some of the templates used can help us determine the dimensions and the exact position of the screen in the captured image. For example, since the template No. 11 identifies the right side of the screen's border, the horizontal mean value of the template No. 11 estimates the rightmost position of the screen. Likewise, this technique can be used for the other sides of the screen with templates No. 14, 7 and 13.

Obtaining vertical adjustment parameters: We can obtain the values of the adjustment parameters using the dimensional and positional characteristics of the TV screen in the image. To measure the adjustment parameters, first we generate an appropriate pattern on the TV screen. The pattern generated depends on the proposed adjustment parameter that we want to obtain. The position of the applied pattern on the screen is then determined using the maximum gradient edge detection algorithm (Parker, 1997; Meade and Webb, 1998).

For example suppose we generate the pattern of vertical size adjustment parameter as shown in Fig. 8. Starting from the top side of the screen, the maximum gradient edge detection algorithm is applied on several parallel vertical lines of pixels that are limited to the width of the TV screen. Averaging the maximum gradient position of the negative edge-from bright pixels to the dark ones-over these parallel lines results in the location of the used pattern. The obtained pattern location with the top and down side positions of the TV screen is used to calculate the value of the vertical size adjustment parameter (Fig. 3a). The other adjustment parameters are calculated in a similar manner.

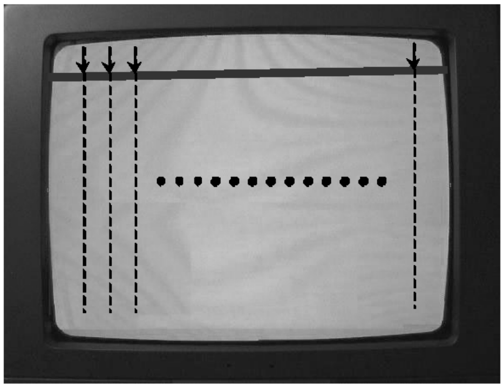

Fig. 8: V-Size pattern and vertical lines of pixels

Obtaining Horizontal Adjustment Parameters: The possible variations in the television-camera relative pose on the production line are such that they can influence the measurement of the horizontal geometric characteristics more than the vertical ones. Therefore, in order to be able to properly measure the horizontal geometric characteristics a few optical points must be carefully considered. Let's assume that we want to measure the deviation of the horizontal centre. We must therefore define the horizontal centre adjustment parameter. Suckle (1988) suggested to generate a vertical line pattern at the horizontal centre. He defined the horizontal centre adjustment parameter similar to the vertical case as shown in Fig. 9.

Since Suckle (1988) did not present any experimental study on this approach, the practical problems with this suggestion were not considered by him. In a practical experimental setup, the defined adjustment parameter would only be correctly measured if the viewing direction of the measurement camera is exactly perpendicular to the surface of the TV screen. Any deviations from this orthogonality condition due to possible television angular displacement moving along on the production line until it reaches the front of the camera where it is temporarily stopped for a few moments would introduce error in measurement. The optical nature of the effect of the angular displacement of the TV screen from the orthogonality condition with the camera viewing direction from the top view is shown in Fig. 10.

Suppose that the point A shows the leftmost side of the screen and the point B represents the rightmost side of the screen. Any angular displacement $\theta°$ of the TV screen from the exact orthogonal direction, results in new states for the rightmost and leftmost sides of the screen

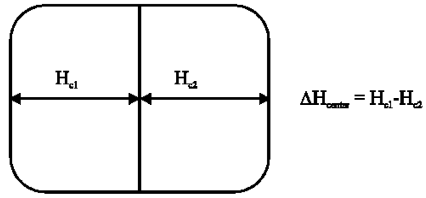

Fig. 9: Preliminary horizontal center pattern and its adjustment parameter

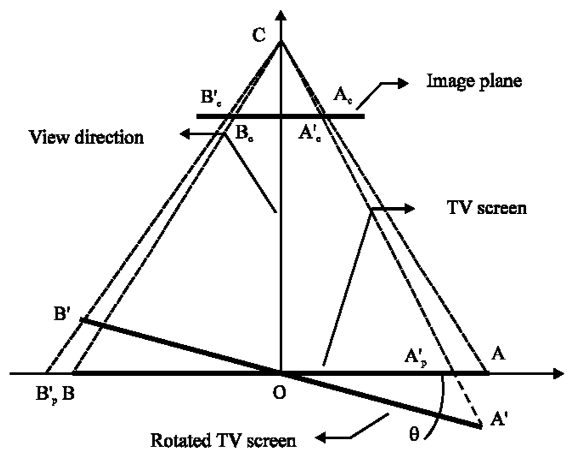

Fig. 10: Optical essence for preliminary H-Center pattern

that are shown by the points A' and B', respectively. The images of the points A and B are the A_c and B_c, respectively that are created on the image plane (Hutchinson *et al*., 1996). For the rotated TV screen case the images of the points A' and B' on the image plane are the A'_c and B'_c, respectively.

To estimate the measurement error due to angular displacement of the screen we consider corresponding imaginary points for the A' and B' on the exact orthogonal direction in such a manner that their images on the image plane are the same as the original ones. One of the imaginary points A'_p is located at the intersection of the ray directed from the pixel at point A' towards the optical centre-point C-with the line AB. The other point B'_p is located at the intersection of the imaginary line from the optical centre towards B' with the line AB. The middle point of the line AB and the line $A'B'$ are coincident. Therefore, this point is the correct horizontal centre of the TV screen for both the exact orthogonal case and the tilted case. The measurement error of the defined horizontal centre adjustment parameter due to angular displacement of the screen from the perpendicularity condition equals to the distance between the middle point of the line $A'_pB'_p$ and the correct centre. The following equations show the calculation of the measurement error of the defined adjustment parameter E_{h1} (θ) by accumulating half of the difference between the length of OA and OA'_p and the difference between the length of OB and OB'_p.

Assumptions:

$$|OA| = |OB| = |OA'| = |OB'| = l$$
$$|OC| = z, \quad z > l, \quad 0 \le \theta < 90$$

$$\begin{aligned} E_{hl} &= (e_1 + e_2)/2 \\ e_1 &= |OA| - |OA'_p| \quad , e_1 > 0 \\ e_2 &= |OB'_p| - |OB| \quad , e_2 > 0 \end{aligned} \tag{1}$$

$$\begin{aligned} \text{Line}_{CA'}: y = -\frac{z + l\sin\theta}{l\cos\theta}x + z \Rightarrow |OA'_p| = \frac{zl\cos\theta}{z + l\sin\theta} \\ \Rightarrow e_1(\theta) = l - \frac{zl\cos\theta}{z + l\sin\theta} \end{aligned} \tag{2}$$

$$\begin{aligned} \text{Line}_{CB'}: y = \frac{z - l\sin\theta}{l\cos\theta}x + z \Rightarrow |OB'_p| = \frac{zl\cos\theta}{z - l\sin\theta} \\ \Rightarrow e_2(\theta) = -l + \frac{zl\cos\theta}{z - l\sin\theta} \end{aligned} \tag{3}$$

$$(1,2,3) \Rightarrow E_{hl}(\theta) = \frac{zl^2\cos\theta\sin\theta}{z^2 - l^2\sin^2\theta} \tag{4}$$

In order to minimize the error due to any deviations from orthogonality we define an appropriate horizontal centre adjustment parameter by considering a pattern with a pair of vertical parallel lines near the sides of the screen. The corresponding adjustment parameter ΔH_{center} is described in Fig. 11.

Figure 12 shows the optical nature that is used to calculate the measurement error of the suggested adjustment parameter. The points M and N represent the two vertical parallel lines on the pattern that have the same distance from the horizontal centre O. The

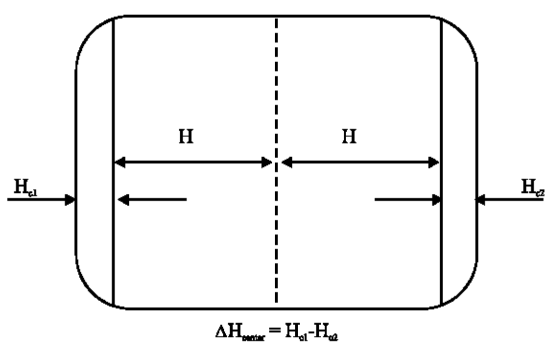

Fig. 11: Preferred horizontal center pattern and its adjustment parameter

measurement of the horizontal centre adjustment parameter by the use of the recommended pattern is based on the length of BN and MA that are corresponding to the H_{c1} and H_{c2}, respectively in Fig. 11. Suppose that the points M and N are at the same distance d from the points A and B, respectively. As shown in Fig. 10 the angular displacement $\theta°$ of the TV screen from the exact orthogonal direction is shown by points A' and B'. The imaginary points A'_p, M'_p, N'_p and B'_p on the exact orthogonal direction are considered instead of A', M', N' and B', respectively. The measurement error E_{h2} (θ) of the recommended horizontal centre adjustment parameter due to angular displacement of the screen equals to the sum of the difference between the length of MA and $M'_pA'_p$ and the difference between the length of BN and $B'_pN'_p$ as follow:

Assumptions:

$$|OA| = |OB| = |OA'| = |OB'| = l$$
$$|MA| = |NB| = |M'A'| = |N'B'| = d$$
$$|OC| = z, \quad z > l, \quad l > d, \quad 0 \le \theta < 90$$

$$\begin{aligned} E_{h2} &= (e_1 + e_2)/2 \\ e_1 &= d - d'_1, \quad d'_1 = |M'_pA'_p|, \quad e_1 > 0 \\ e_2 &= d'_2 - d, \quad d'_2 = |N'_pB'_p|, \quad e_2 > 0 \end{aligned} \tag{5}$$

$$\begin{aligned} \text{Line}_{CM'}: y = -\frac{z + (l-d)\sin\theta}{(l-d)\cos\theta}x + z \Rightarrow |OM'_p| = \frac{z(l-d)\cos\theta}{z + (l-d)\sin\theta} \\ \Rightarrow d'_1 = \frac{zl\cos\theta}{z + l\sin\theta} - \frac{z(l-d)\cos\theta}{z + (l-d)\sin\theta} \end{aligned} \tag{6}$$

$$\begin{aligned} \text{Line}_{CN'}: y = \frac{z - (l-d)\sin\theta}{(l-d)\cos\theta}x + z \Rightarrow |ON'_p| = \frac{z(l-d)\cos\theta}{z - (l-d)\sin\theta} \\ \Rightarrow d'_2 = \frac{zl\cos\theta}{z - l\sin\theta} - \frac{z(l-d)\cos\theta}{z - (l-d)\sin\theta} \end{aligned} \tag{7}$$

$$(5,6,7) \Rightarrow E_{h2}(\theta) = \frac{zl^2\cos\theta\sin\theta}{z^2 - l^2\sin^2\theta} - \frac{z(l-d)^2\sin\theta\cos\theta}{z^2 - (l-d)^2\sin^2\theta} \tag{8}$$

By comparing the two error Eq. (4) and (8) we have:

$$E_{h2}(\theta) = E_{hl}(\theta) - T(\theta) \tag{9}$$

Where:

$$T(\theta) = \frac{2z(l-d)^2\sin\theta\cos\theta}{z^2 - (l-d)^2\sin^2\theta}$$

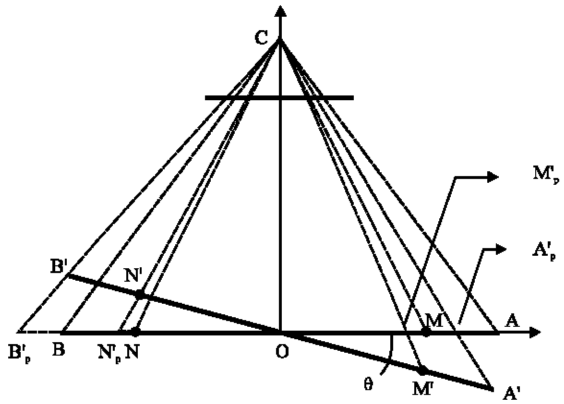

Fig. 12: Optical essence for chosen H-Center pattern

E_{h1} (θ) and T (θ) have non-negative values since 0≤θ<90, z<1 and l>d. In addition T (θ)≤E_{h1} (θ). Therefore, it is clear that 0≤E_{h2} (θ) ≤E_{h1} (θ). By decreasing d, T (θ) approaches E_{h1} (θ) and E_{h2} (θ) vanishes.

$$\lim_{d\to 0} T(\theta) = E_{h1}(\theta) \Rightarrow \lim_{d\to 0} E_{h2}(\theta) = 0 \quad (10)$$

Actually if we desire to be able to measure from the image that is created by a CCD, we cannot arbitrary decrease d since its projection must at least occupy several consecutive discrete cells of the CCD plane. Thus if we use present definition of the horizontal centre adjustment parameter as shown in Fig. 11, the measurement error due to angular displacement cannot be totally eliminated. However, it can be effectively reduced.

PARAMETERS ADJUSTMENT ALGORITHM

After the measurement phase, the digital controller must generate proper control signals based on the errors between the set points and the corresponding measured adjustment parameters in order to adjust the geometric parameters of the TV screen. The digital controller uses the resultant errors to create proportional control signals (Sznaier Camps, 1998; Chroust *et al*., 2000). The exact loop gain of each adjustment parameter is related to its corresponding structure.

The process of the measurement and the generation of the control signals must be repeated until the error between the desired values and the measured parameters is reduced to an acceptable level. Note that each adjustment parameter has its own specific acceptable error level.

The spatial discrete structure of the plant and the measurement process cause the closed loop system to be unstable in some situations. Suppose that the two nearest adjacent values of a measured adjustment parameter of the desired value are such that the corresponding error value cannot fall in the acceptable limit which leads to an unstable state. To overcome this problem, we use an adaptive mechanism for the acceptable error. If at the adjustment process, a measured adjustment parameter value changes between two consecutive values for several iterations, then an unstable state is detected. This can be used for widening the acceptable error. In every iteration that an unstable state is detected, the acceptable error level is smoothly increased. This procedure is continued until the measured error falls in the increased acceptable error level.

As was previously said, some of the geometric parameters of the TV screen are related to each other. In the designed system, the adjustment parameters have been simply modeled separately and the existing mutual effects between the adjustment parameters has not been considered. So the adjustment process must be applied several consecutive times until the adjustment parameters converge to the desired values. This convergence is guaranteed since the value of every mutual effect factor is less than one.

EXPERIMENTAL RESULTS

The system described has been utilized to implement the presented algorithms. The designed system has been installed on the production line of the 14 Pars colour television at Sirjan Electronics Company in Iran. This system has successfully undertaken the automatic adjustment task of the geometric parameters and the white balance of the TV screen in the manufacturing production line. The total adjustment process contains all horizontal and vertical geometric parameters as well as colour adjustment parameters. It is carried out in less than 1.5 min which shows a fivefold improvement over previous manual adjustment methods at an increased precision.

CONCLUSIONS

In this study we have presented the application of previously published novel fuzzy test pattern and adaptive alignment approach presenting a novel design for an auto-alignment system for the television sets which we have practically implemented on a real production line. The problems encountered were explained and the suggested solutions were utilized in designing the system. Present alignment algorithms take only relative measurements that require no camera calibration. Therefore, an uncalibrated camera can be used to obtain the misalignment information in the closed-loop structure. We considered several points for defining the adjustment parameters to reduce the measurement error and utilized proportional digital control rules with adaptive error levels to stabilize the process of adjusting the geometric characteristics.

We implemented our automatic alignment algorithm and applied it to a production line of the 14" colour television. The experimental results and in-house practical use of our system have shown that our system works well in real setting.

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