Clinical usefulness of super high-resolution liquid crystal displays using independent sub-pixel driving technology

doi: 10.1007/978-3-540-70538-3_13

Clinical Usefulness of Super High-resolution liquid crystal displays using Independent Sub-pixel Driving Technology

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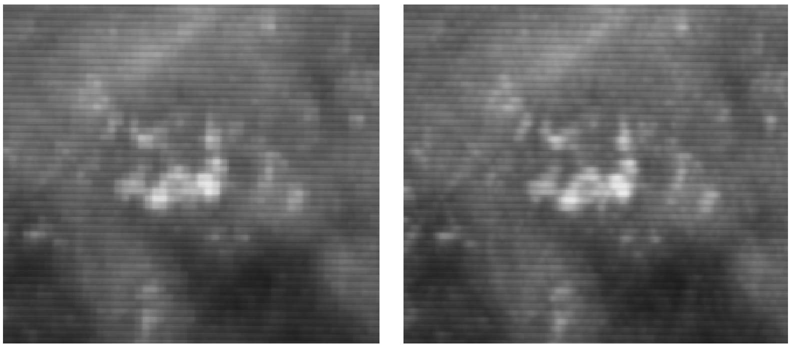
Abstract. We have developed and reported super-high resolution liquid crystal displays (SHR-LCDs) using a new resolution enhancement technology of the independent sub-pixel driving (ISD) that utilizes three sub-pixels contained in each pixel element. This technology realizes the three-times resolution enhancement of monochrome LCDs. A 15 mega-pixel (MP) SHR-LCD out of a 5MP LCD and a 9MP SHR-LCD out of a 3MP LCD, for example, are realized by this technology, which improves the depiction ability of detailed image shapes such as micro-calcifications of a mammography. Furthermore, the ISD technology brings not only resolution enhancement but also noise reduction effect by the high-frequency data sampling in displaying the clinical images. In this study, we have investigated the clinical efficacy of the SHR-LCDs by means of phantom observation studies and blind observer comparison studies using clinical mammography images performed by radiologists. We used a conventional 5MP LCD for a comparison of a 15MP SHR-LCD and a 9MP SHR-LCD to evaluate their efficacy. From the results of the studies, it was indicated that the SHR-LCDs using the ISD technology had the excellent ability to display the high-resolution digital mammography images.

Keyword: liquid crystal display (LCD), resolution, sub-pixel, digital mammography

1 Introduction

Recently, the resolutions (matrix sizes) of flat-panel detectors (FPDs) and the computed radiography systems (CRs) for digital mammography have already been in the range from 13 - 65 mega-pixels (MP). However, even 5MP monochrome liquid crystal displays (LCDs), the highest resolution displays, do not have the enough resolution properties (matrix size) to meet the mammography system's resolution. In order to improve these situations, we have developed the super-high resolution liquid crystal displays (SHR-LCDs) using a new resolution enhancement technology, Independent Sub-pixel Driving (ISD)[1,2]. Each pixel of monochrome LCDs consists of three sub-pixels that are equivalent to RGB sub-pixels of color LCDs [3,4]. Driven each sub-pixel by pixel value corresponding to information recorded in the FPD or CR image, the three times resolution enhancement is achieved. Using this ISD technology, we developed a 15MP out of a current 5MP LCD and a 9MP SHR-LCD out of a current 3MP LCD without any change of their pixel structures. As shown in Fig.1, the SHR-LCD provides higher image qualities compared with the conventional LCD. The physical characteristics of these SHR-LCDs were already examined, and their higher resolution properties were established [1,2]. Moreover, the noise reduction effect in the clinical image was reported [5]. However, the detailed investigation of the clinical efficacy for the digital mammography should be needed, because the resolution in only one direction corresponding to the sub-pixel chain direction was enhanced in the SHR-LCDs. In this study, we investigated the clinical usefulness of the SHR-LCDs by means of the CDMAM phantom observation studies, the detection studies using simulated small objects and the blind comparison studies performed by radiologists using clinical mammography images. Mainly, we compared a 15 MP SHR-LCD with a conventional 5MP-LCD, and in some phantom comparison studies, a 9MP SHR-LCD were examined together.



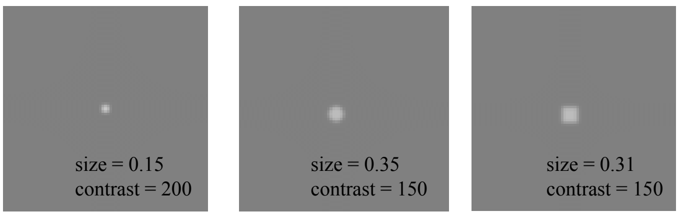
(a) (b)

Fig.1. Micro-calcification images in a clinical digital mammography displayed on (a) the conventional 5MP LCD and on (b) the 15MP SHR-LCD equipped with the ISD.

2 Methods and materials

In the first study, a 15 MP SHR-LCD were examined to compare with a conventional 5MP LCD using a CDMAM phantom. A clinical full-field digital mammography system (MAMMOMAT Novation DR, Siemens) was used to acquire a digital CDMAM image. Two additional acrylic plates of 1.0 cm were placed on and under the phantom respectively at imaging. The imaging conditions were selected as 28kV, 50 mAs, Mo/Mo filter. The obtained image was displayed on the respective LCDs by using the dedicated viewing software which is implemented with the image-rendering algorithm corresponding to the ISD technology. The phantom reading was performed at various display magnification levels with sub-sampling ratios (SR) in the range from 0.45 to 1.0. The SR of 1.0 means a pixel-by-pixel displaying, which commonly presents a large magnification display image, and the smaller sub-sampling ratios than 1.0, in which skipped sampling from the original data with the sampling interval corresponding to the SR value creates the image data for displaying, result in a loss of data. The SR values for the SHR-LCDs were adapted to normal LCD pixel size rather than the sub-pixel size in order to realize the same size of displayed images. Therefore, in the same SR value, the data sampling density in the sub-pixel direction of the SHR-LCD is three times more than the conventional LCD, and the finer image depiction is realized on the SHR-LCD. The interpolation method used in the data sampling was bilinear interpolation in the all displaying. Six readers consisting of one medical physicist and five mammography technicians scored the images to evaluate. The room luminance was set to about 10 lx. The distance and time of observation were not restricted. All observation results were synthesized and then used in calculating the image quality figures (IQFs).

In addition, we carried out two detection studies. In the two studies, the 15MP SHR-LCD, 9MP SHR-LCD and 5MP LCD are compared together. The common methodology for the two methods was based on observation of a simulated small object implanted numerically into the actual noise image that was obtained from a uniform acrylic phantom. The simulated small object in the shape of a round or a square was processed by a blurring function measured from mammography system used in this study, and added numerically to the noise image at a specified position. The digital value contrast to background and size of the object were arbitrarily given during the object creating process. One study was a task to detect the small round shape object with a diameter of 0.15mm and a digital value contrast of 200. The object appeared in a random position during five-second observation time per one image appearance, and the observer pointed the correct position of the object by computer-mouse clicking. The observers were forced to evaluate 100 images for each of three SR conditions; 0.43, 0.55 and 1.0. The other study was a task to discriminate which shape (round or square) of the simulated object appears on the display. The sizes of the round and square shapes were set to 0.35 and 0.31 respectively so that the two shapes gave the same area. The digital contrast value of 150 was used for two shapes in common. The observers read 100 images for each of three SR conditions same as the former detection study. The correct detection and discrimination rates were compared between the three LCDs. The observation environments such as the distance were same as the CDMAM reading. Fig.2 shows the original small objects' image used in the detection and shape discrimination studies.



(a) (b) (c)

Fig.2. Original simulated object images for the (a) detection and (b,c) shape discrimination studies.

In the blind comparison study using clinical mammography images, 100 medio-lateral oblique (MLO) view images of 50 cases (right and left images for 1 case) containing the micro calcifications are used. The same images were displayed on the 15MP SHR-LCDs and the 5MP LCD by using a dedicated image viewing software which provides functions to synchronize the magnification and the window condition in the compared two displays. The following two steps were provided to the examinations: 1. The SR condition was limited to 0.55. 2. Free magnifying conditions. The windowing, distance and time of the observation were not restricted. The observers were five doctors and five radiologists who are grade-A qualified by the Central Committee on Quality Control of Mammographic Screening in Japan. The 5-point scale (-2: inferior, -1:worse, 0: equivalent, 1:better, 2:superior) was used to determine effectiveness of the two LCDs of 15MP and 5MP when the physicians analyzed the existence and shape of micro-calcifications.

3 Results

Fig.3 is a result of the comparisons of averaged IQFs of six readers and p-values of respective SR conditions. There are significant differences ($p<0.05$) in the SR conditions of 0.43, 0.55 and 0.73. As regards individual recognition results in the small SR values of 0.43 and 0.55, the minimum diameters for thick thickness (> 0.1mm) on the 15MP SHR-LCD were lower than those of the 5MP LCD. Fig.4 and Fig.5 show the results of the detection and discrimination studies using the simulated objects. In the detection study, the detection rates for the 15MP SHR-LCD were higher than the 5MP LCD in the SR conditions of 0.43 and 0.55. The shape discrimination study showed that the 15MP SHR-LCD had excellent depiction ability for small objects.

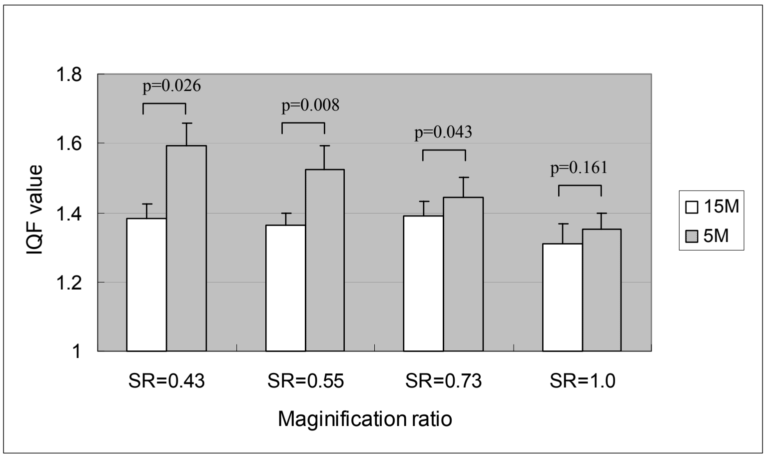


Fig.3. Result of the comparisons of averaged IQFs of six readers for respective sub-sampling ratios

In both studies, there is no significant difference between the 5MP and the 9MP SHR-LCD in the all SR conditions. Table1 shows the results of blind comparison study between the 15MP SHR-LCD and the 5MP LCD. The positive values (+2 and +1) mean that the better evaluations were given to the 15MP SHR-LCD than the 5MP LCD.

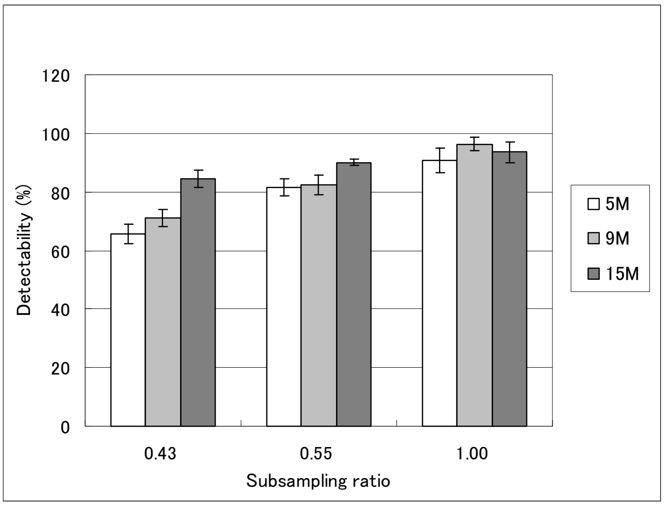


Fig.4. Detectabilities of the simulated disc object of 0.15mm in the three SR conditions

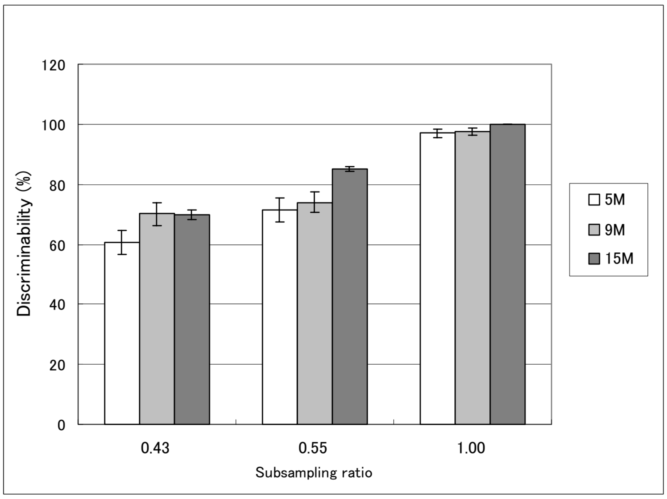


Fig.5. Shape discrimination ability of simulated round or square objects of 0.35mm in the three SR conditions.

Table 1. Results of the blind comparison study between the 15MP SHR-LCD and the 5MP LCD using the clinical mammography images

	Existance		Shape	
Evaluated Scale	SR= 0.55	Free magnifying	SR= 0.55	Free magnifying
+2	1.4	1.6	13.2	7.2
+1	35.8	19.8	62.6	45.2
0	61.8	78.2	24.2	46.2
-1	1.0	0.4	0	1.4
-2	0	0	0	0
Sum of +1 and +2	37.2	21.4	75.8	52.4

4 Discussion

From the CDMAM phantom study, in the small magnification levels, the 15MP SHR-LCDs presented higher detectabilities than the 5MP LCD. It was suggested that the enhanced resolution by the sub-pixel rendering in the SHR-LCDs produced the improvements. The advantages of the 15MP SHR-LCD were supported by the results that the relation of the SR conditions and the detectabilities were similar in the detection study using the simulated object and the CDMAM phantom study. These results indicated that the resolution improvement in only one direction corresponding to the sub-pixel chain direction increases a certain ability of small signal detections. Though the 9MP SHR-LCD has more total pixel (sub-pixel) number than the 5MP LCD, the two LCD showed almost the same performances in the both detection and shape discrimination studies. These results indicated that the resolution enhancement in only one direction provided a reduced resolution enhancement not meeting its increase of the total pixel number. Actually, since we could predict the degree of the resolution enhancement to a certain extent, these results about the 9MP SHR-LCD were enough acceptable for us. Since the 9MP SHR-LCD is produced from a 3MP LCD panel without any hardware change, the price will able to be set to lower than the 5MP LCD. Therefore, we believe that the performance of the 9MP SHR-LCD is very important for the soft-copy diagnosis environment. The results of the shape discrimination study showed interesting properties. While the detection study showed the highest differences between 5MP LCD and 15MP SHR-LCD in the SR condition of 0.43, in the shape study, this SR condition provided the small differences between the all LCDs. We supposed that the reason was that the pixel number to display the simulated small objects was too small to depict their correct shape even in the 15MP SHR-LCD. Although the sub-pixels try to depict the correct shape of the small objects, the unchanged resolution in the non sub-pixel direction obstructs the correct shape reproduction. This phenomenon indicated the limitation of the image rendering using the sub-pixels. From the blind comparison study, in case of SR=0.55, ”Superior” or ”Better” was given to the 15M LCD in 38% of the cases in the existence evaluation. In the shape evaluation, the 15M LCD was rated above ”Better” in 76% of the cases. Since the CDMAM phantom study and the detection study indicated that the levels of 15MP SHR-LCD for SR=0.55 were almost same as the 5MP LCD for SR=1.0 (pixel-by-pixel displaying), it was more clearly clarified that the 15MP SHR-LCD in case of SR=0.55 provided the high depiction ability. The SR condition of 0.55 provides an average magnification level which is applied in popular clinical mammographic viewer when four images (two CC and MLO images) are initially loaded. Therefore the results for this SR condition were very important in that the image reader can obtain the more information from the 15MP SHR-LCD than the 5MP LCD. These results showed that the SHR-LCDs are clearly beneficial in the clinical image diagnosis. In this study, the evaluation for the 9MP SHR-LCD was not enough. Though the studies using the simulated small objects suggested that the 9MP SHR-LCD have almost same performance as the 5MP LCD, we will need further examinations using clinical mammographies.

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