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Development of a new resolution enhancement technology for medical liquid crystal displays

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ABSTRACT

A new resolution enhancement technology that used independent sub-pixel driving method was developed for medical monochrome liquid crystal displays (LCDs). Each pixel of monochrome LCDs, which employ color liquid crystal panels with color filters removed, consists of three sub-pixels. In the new LCD system implemented with this technology, sub-pixel intensities were modulated according to detailed image information, and consequently resolution was enhanced three times. In addition, combined with adequate resolution improvement by image data processing, horizontal and vertical resolution properties were balanced. Thus the new technology realized 9 mega-pixels (MP) ultra-high resolution out of 3MP LCD. Physical measurements and perceptual evaluations proved that the achieved 9MP (through our new technology) was appropriate and efficient to depict finer anatomical structures such as micro calcifications in mammography.

Keywords: liquid crystal displays (LCD), pixel, sub-pixel, resolution, modulation transfer function (MTF)

1. INTRODUCTION

Recently, the resolution (matrix size) of flat-panel detectors (FPDs) and computed radiography systems (CRs) have already achieved about 12 mega-pixels (MP) and higher. Farthermore, in advanced digital mammography systems, the resolution reached beyond 16MP. In sync with these developments of digital modalities, diagnostic soft-copy reading is becoming widely spread in medical fields, and liquid crystal displays (LCDs) are becoming the standard in modalities instead of X-ray films and laser printer films. However, even 5MP LCDs do not have enough resolution properties that are required of FPD and CR systems. Therefore, radiologists are forced to observe the sub-sampled images on the LCDs, and for more accurate soft-copy diagnosis, a demand for LCDs with higher resolution properties is increasing. In order to solve this problem, we developed a new resolution enhancement technology for medical monochrome LCDs that utilizes sub-pixels in each pixel element. Color LCDs consist of a large number of pixel elements, each of which has has three sub-pixels: R, G, and B for the color representation. Using the same color LCD panel, monochrome LCDs have the same sub-pixels but only without the color filters. However, these monochrome sub-pixels are driven at the same signal level to represent monochrome images and there is no control over individual sub-pixels. We have noticed the potentiality of using sub-pixels for resolution enhancement and developed a monochrome 3MP LCD with the independent sub-pixel driving (ISD) capability just like a color LCD. We then realized a 9MP ultra high-resolution LCD by combining a computer program that enhances resolution through the ISD. In other words, we succeeded in tripling resolution in monochrome LCDs without changing the existent pixel structure. In this paper, we describe the new resolution enhancement technology and the newly developed 3MP LCD that realizes 9MP resolution, and report its measured physical performances and initial perceptual evaluation results.

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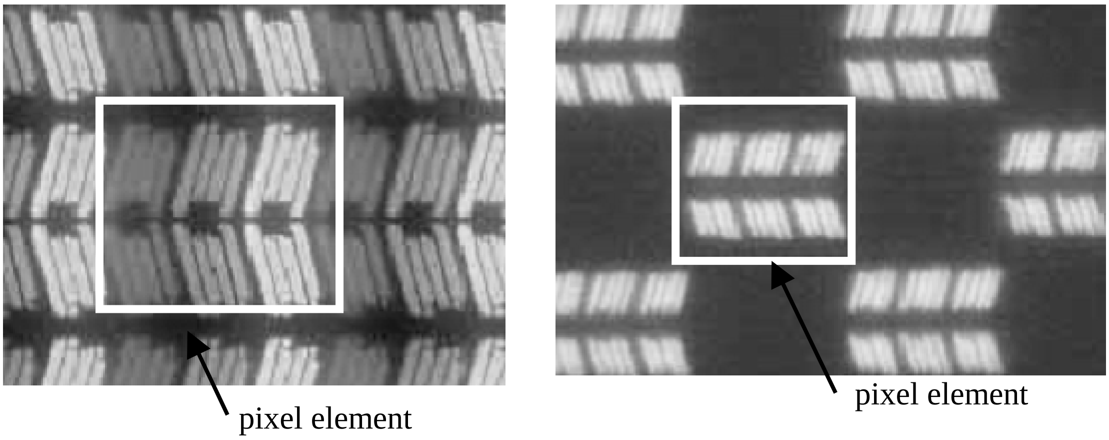
2. MATERIALS AND METHODS

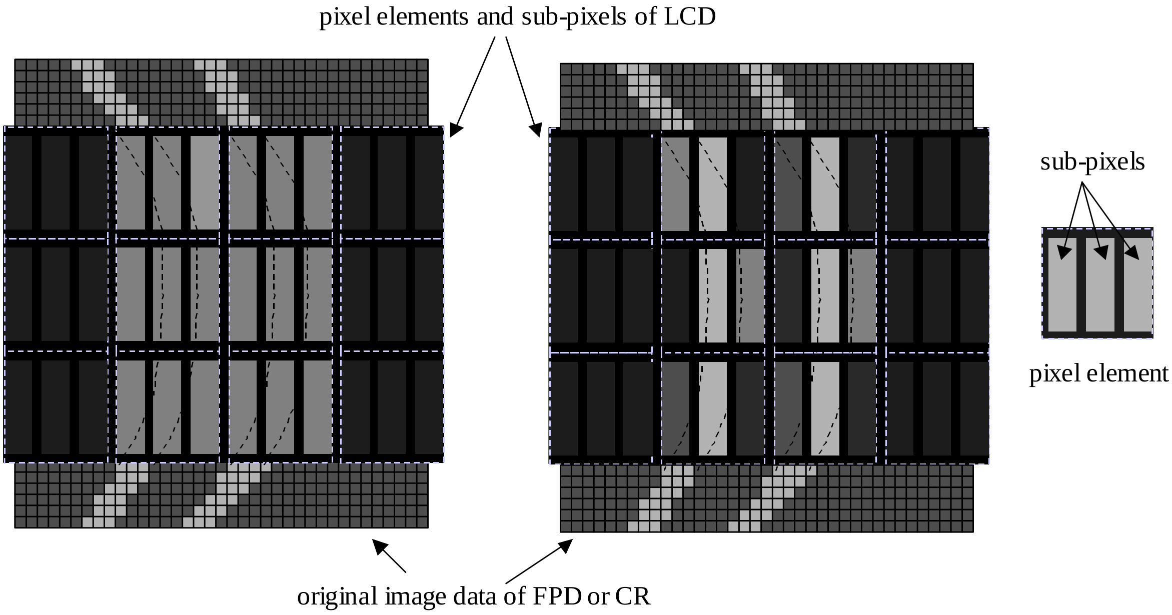
2.1. Pixel structure of color LCD and monochrome LCD

Figure 1 shows examples of pixel structures of a color and a monochrome LCD. As shown in this figure, the sub-pixels form a line in horizontal direction and have very small size and pitch of one part in three for one pixel element. In the newly developed LCD, these sub-pixels are treated as pixel elements and driven by detail anatomical information recorded in image data of FPDs and CRs. Therefore, tripling resolution enhancement is achieved without changing the existent pixel structure and many effective specifications, such as maximum luminance and view angle, provided originally.



(a) color LCD (b) monochrome LCD

Fig.1. Examples of pixel structure of (a) a color LCD and (b) a monochrome LCD.

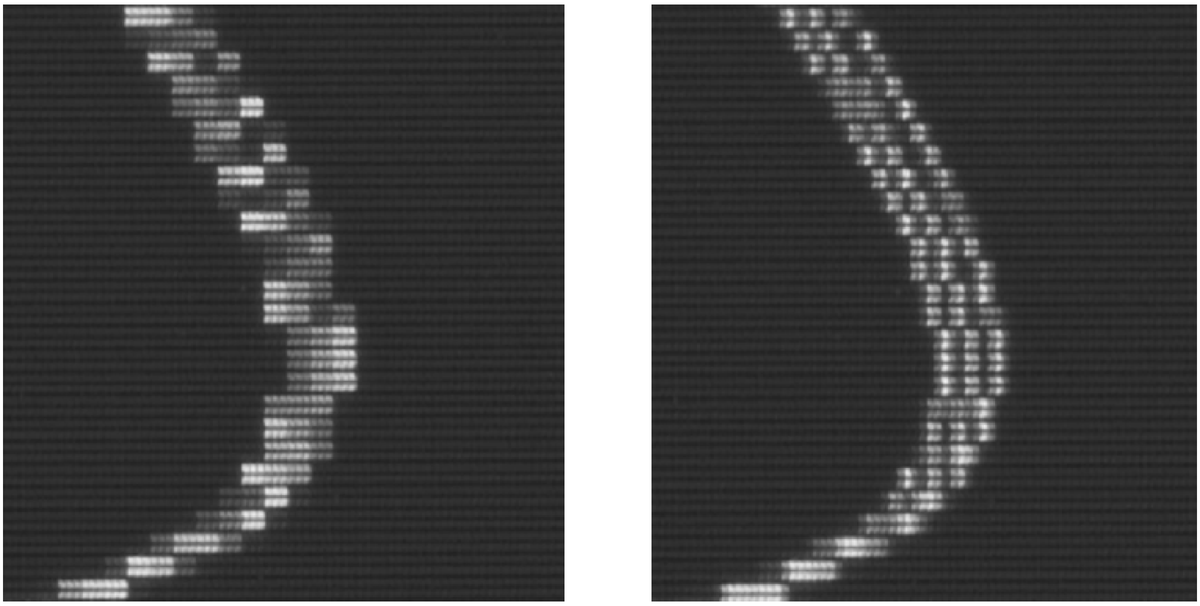


Conventional LCD (without ISD) **With ISD**

Fig.2. Resolution enhancement mechanism by the ISD. Two curved line data are not distinguishable on a conventional LCD. Using the ISD, resolution is improved and consequently the lines are distinguishable.

2.2. Mechanism of the resolution enhancement

Figure 2 shows the mechanism of the resolution enhancement using the ISD. Driven each sub-pixel by pixel value corresponding to detailed information recorded in the FPD or CR image, the three times resolution enhancement is achieved. Since sub-pixels are arranged linearly in most of LCDs, resolution can only be enhanced in one direction (horizontal or vertical). Assume the two curved lines shown in Figure 2 (a) and (b) represent fine anatomical shapes. It is difficult for a conventional LCD to draw the two lines distinctly because they are too close compared to its pixel pitch {Figure 2(a)}. On the other hand, the newly developed LCD, which has very fine sub-pixel pitch, can draw the closely adjacent lines very distinctly as shown in Figure 2(b). Figure 3 shows captured images of three curved lines on a conventional 3MP LCD and the resolution-enhanced 9MP LCD with the ISD function. The same effect as shown in Figure 2 is obtained.



(a) (b)

Fig.3. Comparison of three curved lines displayed on a conventional 3MP LCD (a) and a resolution-enhanced 9MP LCD. They were photographed by a digital camera equipped with a macro lens.

Fig.4. The newly developed resolution-enhanced 9MP LCD (TOTOKU ME351i base)

2.3 Experimental methods

The 9MP ultra high-resolution LCD with the ISD capability was developed from a TOTOKU 3MP monochrome LCD "ME351i" (matrix size of 2048 x 1536, pixel size of 0.207 mm). In order to evaluate the physical performances and clinical efficacy of this 9MP LCD, a DICOM viewing software that implements computer algorisms that corresponds to the ISD was developed. Figure 4 shows the resolution-enhanced 9MP LCD displaying two identical test photos using the DICOM viewing software. The software is capable of not only displaying images with or without the ISD function, but also displaying both images side-by-side: one with the ISD (on the left) and the other without the ISD (on the right). Horizontal and vertical resolution properties were measured by a modulation transfer function (MTF) measuring method using bar-pattern image proposed in a previously published paper (1). In this study, a bar-pattern image displayed on the LCD was photographed by a single-lens reflex digital camera (D80, Nikon Corp.) equipped with a micro lens (Micro Nikkor f2.8/60mm, Nikon Corp.), and MTF values were calculated by analyzing the CCD data. The camera has a CCD with 3872 x 2592 pixels with a pixel depth of 12bit. The maximum magnification was applied so that the sampling pitch would becomes small enough for one sub-pixel width of 0.069 mm. To verify the efficacies of the ISD, several test photos and clinical images were displayed on the LCD and perceptually evaluated with and with out the ISD.

2.4 Resolution improvement by a data processing

The resolution enhancement by the ISD is carried out for only in the same direction as the sub-pixel chain direction, resulting in a disproportion between horizontal and vertical resolutions. To reduce the disproportion, we improved the resolution in the direction perpendicular to the sub-pixel chain direction through a data processing. Although application of this improvement method is limited to frequencies below the Nyquist frequency at actual pixel size, we thought that this method would be useful for an image to appear natural on the screen. The degree of resolution improvement was determined by calculating the ratio of horizontal and vertical MTF results.

3. RESULTS

Figure 5 shows a comparison of partially captured images of the test photos displayed with and without the ISD. The test photo has 2000 x 2500 pixels and was displayed on the LCD by the comparing mode as shown in Figure 4.

(a) ISD-off (b) ISD-on

Fig.5. Comparison of captured images of a test photo displayed on the LCD

Since the images are displayed to fit in half size of the screen, the one without the ISD is only sub-sampled with a matrix size of about 1000 x 1500. In contrast, the image with the ISD showed excellent image quality because of the three-times resolution enhancement.

Figure 6 shows the comparison of measured MTFs with the ISD being turned on and off. The resolution in the horizontal direction (sub-pixel chain direction) was significantly improved due to very fine sub-pixel width of 0.069 mm. Since the pixel size in the vertical direction does not changed, there was no change in vertical MTF. Figure 7 includes a vertical MTF that was enhanced by data processing. Disproportion between horizontal and vertical resolution were reduced below the Nyquist frequency of vertical direction. Figure 8 represents captured images of a digital mammogram obtained by a FPD system, GE Senographe 2000D. The ISD significantly improved the clarity and brought out more details of micro-calcifications. Figure 9 shows the captured images of another mammogram of micro-calcifications, taken by an FPD system, SIEMENS MAMMOMAT Novation DR, to verify effectiveness of applying the ISD and the vertical resolution enhancement by data processing. The image on the left was improved only by data processing in both horizontal and vertical direction without the ISD. The image on the right was enhanced with the ISD and the vertical resolution enhancement. The image on the left contains many disturbing pixelized shapes and noise. In contrast, the image on the right presents no noticeable artifacts and appears very natural.

Figure.10 is a bone X-ray image obtained by a FPD system, Philips Digital Diagnost. The ISD helped the bone trabecular structures appear more clearly.

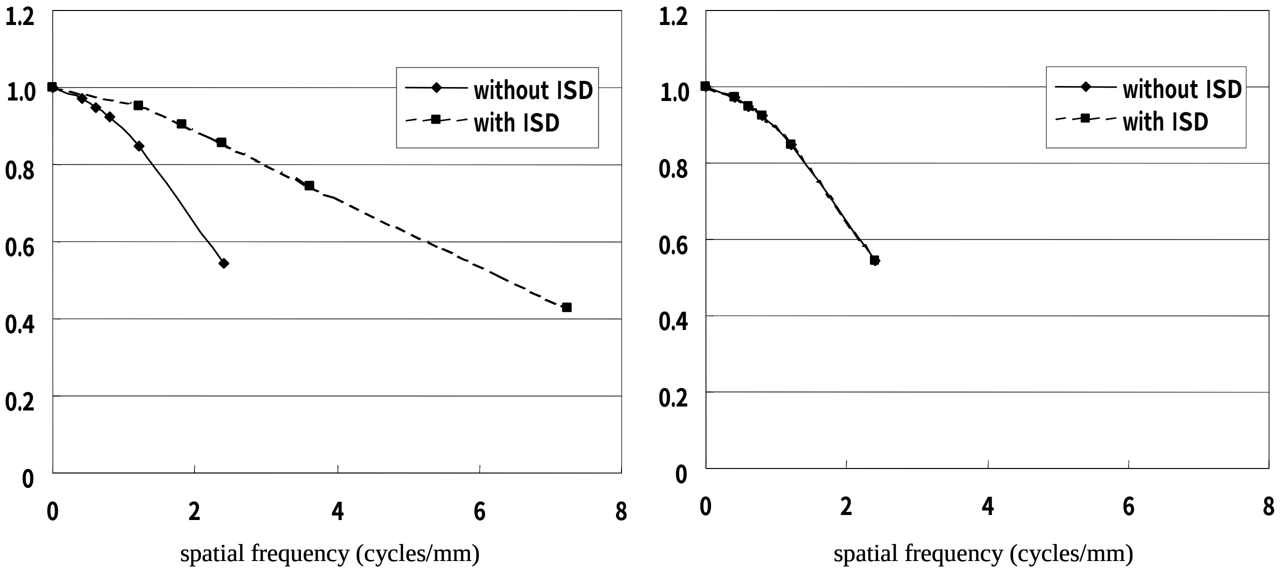


Fig.6. Measured horizontal and vertical MTFs with and without the ISD

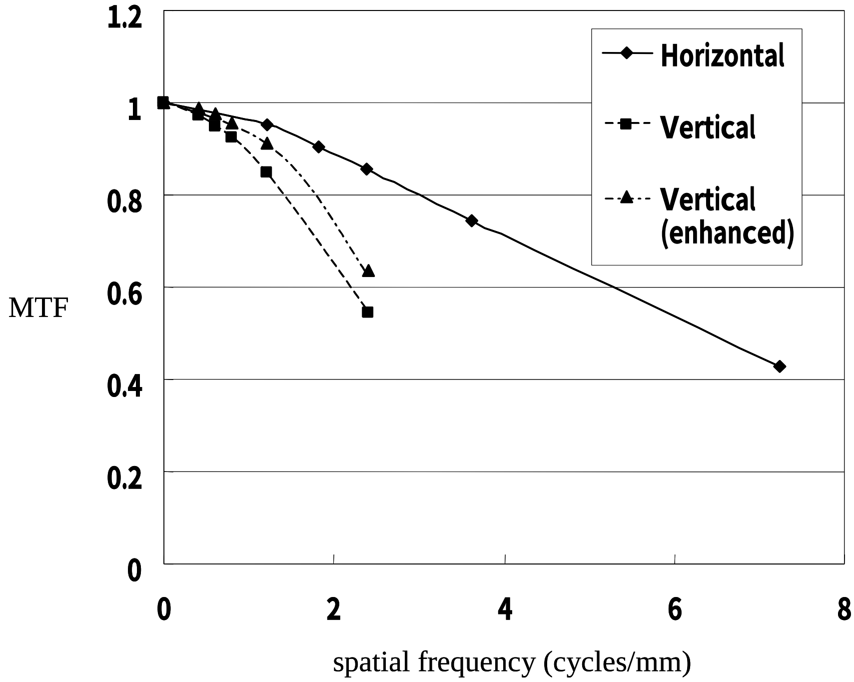


Fig.7. Horizontal and vertical MTFs and a vertical MTF in case of applying enhancement by data processing

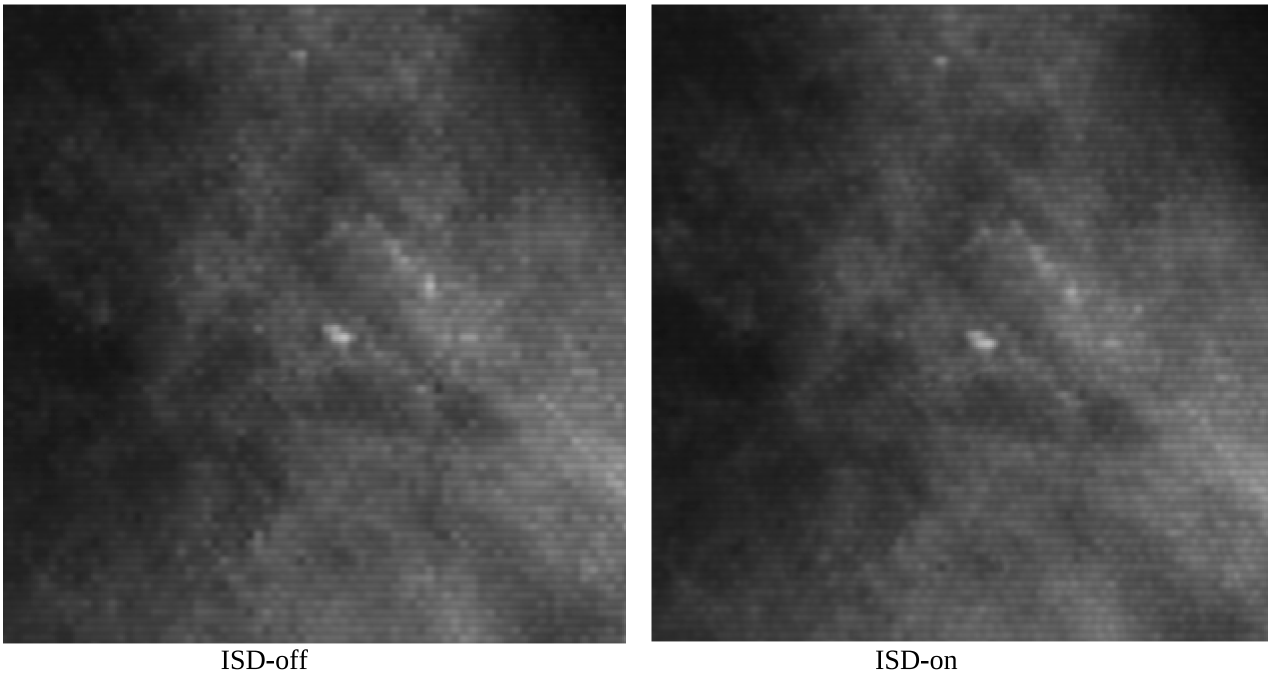
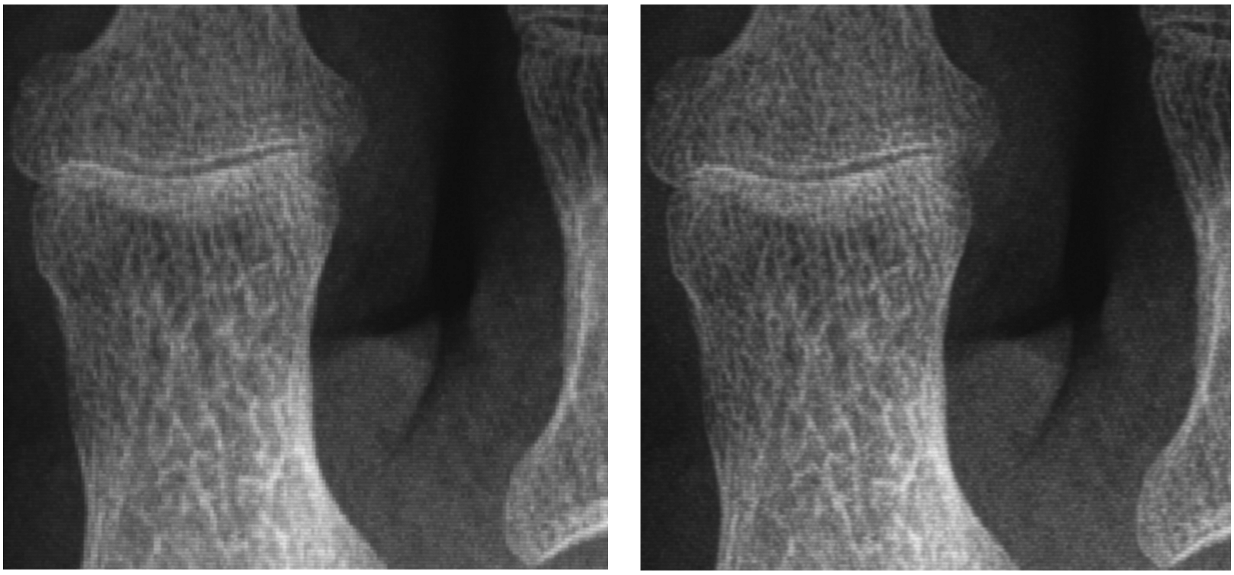
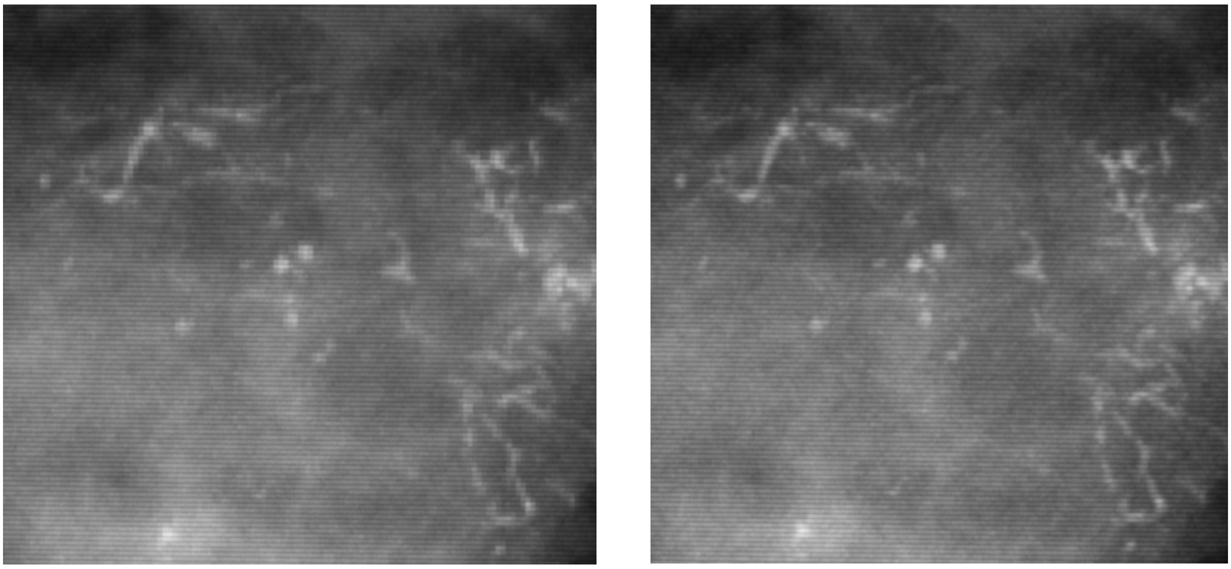


Fig.8. Close-up images of digital mammogram obtained by a FPD system, GE Senographe 2000D.



(a) (b)

Fig.9. Mammograms that include micro-calcifications to verify effectiveness of applying the ISD and the vertical resolution enhancement by data processing. (a) is enhanced only by data processing in both horizontal and vertical directions, without the ISD. (b) is enhanced with the ISD and vertical enhancement.



ISD-off ISD-on

Fig.10. Bone X-ray image obtained by a FPD system, Philips Digital Diagnost. The bone trabecular structures is depicted more clearly with the ISD tuned on.

4. DISCUSSION

By both the physical measurements and the perceptual comparisons, it was proved that the ISD technology for monochrome LCDs was very effective in improving resolution. The MTFs indicated the significant good resolution properties corresponding to very fine sub-pixel size. The efficacy of the ISD was strengthened by combining vertical enhancement using data processing. In displaying clinical image, noticeable artifacts were not observed, and the ability to render fine anatomical structures was significantly improved. At the beginning, we had a concern that disproportion between horizontal and vertical resolution could cause unacceptable artifacts. Even with the vertical enhancement by data processing to compensate the disproportion, the difference in Nyquist frequency and the 1:3 pixel aspect ratio would have negative influence on image quality. Contrary to our prediction, the 9MP technology offered excellent image quality.

We are planning to develop a 5MP LCD that is capable of display 16MP ultra high resolution. Some more perceptual experiments including the 16MP LCD will be necessary to investigate the clinical efficiency of this new resolution enhancement technology by the ISD.

5. CONCLUSION

We developed a resolution-enhanced 9 MP LCD out of a 3MP LCD using the ISD technology*. The measured MTFs indicated the significant good resolution properties corresponding to the fine sub-pixel size. The efficacy of the ISD was strengthened by application of resolution enhancement through data processing in the direction perpendicular to the sub-pixel chain direction. It eliminated noticeable artifacts from anatomical images. Based on physical measurements and perceptual comparisons, we draw a conclusion that this new resolution enhancement technology by the ISD has an excellent ability to render fine anatomical structures such as the micro-calcifications in mammography and will be of significant importance in clinical image diagnosis.

* Patent applied for

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