Original

Measurement of Modulation Transfer Functions for Liquid Crystal Displays by Rectangular Waveform Analysis

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Introduction

In current medical imaging diagnosis, new diagnostic techniques using image viewers equipped with a cathode ray tube (CRT) display or liquid crystal display (LCD) have replaced the conventional film-based diagnostic techniques. It can be expected that this trend will continue to increase in the future. With this change, it is becoming important to evaluate the characteristics of displays and to carry out maintenance management in medical facilities that use CRT displays and LCDs. Therefore, as one form of determining the image quality of a display, modulation transfer function (MTF) is measured by evaluating sharpness.

The method we used is based on a periodic rectangle wave composition of fundamental frequency and harmonics that are sine waves.¹⁾ The flow of this method is shown in Fig. 1. The profile of a direction perpendicular to the bar of the bar patterns was created from image data and converted into the brightness value. The com-

ponent value of a fundamental frequency, Mn (n : segment number), was calculated from exact integer cycle data extracted from the interpolated profile data. In was calculated from the bar pattern and the background levels measured from two uniform areas. The ratio of Mn to In was calculated for MTF.

This was the method of calculating MTF in the horizontal direction of CRT display. The LCDs are discrete display systems and are composed of individual pixels. Therefore, it is necessary to correct the results of the calculation method for the CRT display system (analog system). We multiplied MTFs by the correction factor, except for those in the horizontal direction of the CRT display.

1. Methods

1-1 Display of bar pattern

We used LCDs of 1M (about 1 million pixels), 2M, 3M, and 5M, and a CRT display with a pixel number of 5M. The table shows the specifications of displays. For

Summary

We measured modulation transfer functions (MTFs) of liquid crystal displays (LCDs) by rectangular waveform analysis. This method consists of taking a picture of the bar pattern on the display surface with a digital camera, and analyzing the picture with a personal computer. The displays used are LCDs of 1M (about 1 million pixels), 2M, 3M, and 5M, and a cathode ray tube (CRT) display with a pixel number of 5M. Two kinds of 2M displays were used, an in-plane switching (IPS) system and vertical alignment (VA) system, from which liquid crystal operation mode differs. MTFs increased as pixels increased. For the LCDs, MTFs in the horizontal direction were higher than those in the vertical direction except for the 2M VA system. For the LCD of the 2M VA system, MTF in a horizontal direction was equal to MTF in a vertical direction. For the displays with the same number of pixels (5M), MTF of a LCD was higher than that of a CRT display. MTFs of LCDs are influenced by the pixel form, pixel composition, and the liquid crystal operation mode.

Key words: Liquid crystal display (LCD), Cathode ray tube (CRT) display, Modulation transfer function

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Fig. 1 Outline of the MTF measurement method using frequency analysis of a bar pattern image.

Table Specifications of displays used in this study.

	Pixel size	Pixel pitch [mm]	Liquid crystal operation mode	Panel maker	Display manufacturer
1M (A)	1280×1024	0.312	IPS	NEC	Data-Ray (Precision 1)
(B)	1280×1024	0.281	IPS	ID-Tech	TOTOKU (ME181L)
2M (VA)	1600×1200	0.255	VA	SHARP	TOTOKU (ME201L)
(IPS)	1600×1200	0.270	IPS	NEC	TOTOKU (ME213L)
3M	2048×1536	0.207	IPS	ID-Tech	BARCO (MFGD3220)
5M (1)	2560×2048	0.165	IPS	ID-Tech	NANAO (RadiForceG51)
(2)	2560×2048	0.165	IPS	ID-Tech	TOTOKU (ME511L)
CRT (5M)	2560×2048	0.147	—	—	BARCO

the 1M LCDs, two kinds differing in the structure of pixels were used, and they were dubbed A and B, respectively. For the 2M display, two kinds also were used an in-plane switching (IPS) system and vertical alignment (VA) system²⁾, from which the liquid crystal operation mode differs.

The test pattern was displayed in the center of the screen, and a photograph was taken using a digital camera (Nikon D1H, D70) and camera equipped with a macro lens (Nikon AF Micro-Nikkor). Figure 2 shows the bar pattern image used as the test pattern. There were five pairs of bars with bar pattern and background luminance levels. Each bar consisted of a 1, 2, 3, 4 and 6-pixel width, respectively. The bar level was 65% of the digital driving level (DDL), and the background level was 35%.

The maximum luminance was set to 450 cd/m² and the minimum luminance to 1 cd/m². The displays were

calibrated according to the DICOM 14 display function standard.³⁾ Therefore brightness of the bar level was about 98 cd/m², and those of the background level were about 21 cd/m².

1-2 Picturing the bar pattern

The measurement environment made the room dark, and luminance was about 0 lx. The bar pattern was displayed at the center of the display. Nothing was displayed in the surrounding area except for uniform the background with low DDL and some icons. Black paper covered the display surface except for the area of the bar pattern, to exclude the influence of illumination.

To lose the inclination to the image, the camera was placed parallel to the display.

We took pictures of a bar pattern in a horizontal direction and a vertical direction. We defined horizon-

Fig. 2 Bar pattern image on display.

tal and vertical directions as portrait position and landscape position, respectively. When we took a picture of the bar pattern, the camera was not rotated, but the displays were rotated.

The distance between displays and the digital camera was adjusted so that a bar pattern would become the same size in the finder. Effective pixel number in the horizontal direction of the digital camera is 3040. We photographed the bar pattern image to become about 2000 pixels in the horizontal direction of the digital camera. At this time, the sampling pitch in the digital camera was 0.008–0.012 mm, and the sample number per one pixel of the display was 21–25.

The shutter speed of the camera was set to 1/5 second. Diaphragm was set to 29. The matrix size of the output image was 3040×2014, and its grayscale was 12 bit. We used RAW data from the CCD for calculation.

1-3 Calculation of MTFs

The data for exact integer cycles of the bar patterns were extracted from an output waveform. The amplitude value Mn of a fundamental frequency of bar pattern was calculated and MTF was computed.

2. Results

Figures 3 and 4 show MTFs of LCDs that have different numbers of pixels with the same structure of sub-pixels as an IPS system. The MTFs were measured to the Nyquist frequency decided from the pixel pitch of a display. MTFs in the horizontal direction are shown in Fig. 3, and those in the vertical direction are shown in Fig. 4. These MTFs were expressed with the spatial frequency corresponding to the real distance on the screen. In the horizontal direction, MTF of 5M was the high-

Fig. 3 MTFs in the horizontal direction of LCDs.

Fig. 4 MTFs in the vertical direction of LCDs.

est, compared with those of 3M, 2M, and 1M. The two MTFs of 5M were almost the same. The MTFs of 1M and 2M were similar in the vertical direction. MTFs of 1M displays of the LCDs that differed in the structure of pixels are shown in Fig. 5. MTFs of 1M(A) exceeded 1 at low frequency. The fluctuation was also large, and their forms were different from other MTFs. MTFs of 2M displays of the LCDs with differences in liquid crystal operation mode are shown in Fig. 6. MTFs of the VA system in the horizontal and vertical directions were almost the same. MTFs of 5M displays of the LCD and CRT displays are shown in Fig. 7. MTFs of the CRT display decreased considerably compared with those of the LCD as frequency increased.

3. Discussion

Enlarged images of pixels are shown in Fig. 8. We found that the shape of a pixel of 1M(A) was diamond-like and differed from other displays. Moreover, the width of a bar with one pixel was effectively narrower than

Fig. 5 MTFs of LCDs of 1M that differ in pixel structure.

Fig. 6 MTFs of LCDs of 2M that differ in the operation mode of liquid crystal.

Fig. 7 MTFs of the LCD and the CRT display of 5M.

Fig. 8 Enlarged pictures of LCDs and the CRT display used in this study.

those of other displays. Therefore, we consider that the MTFs of 1M(A) increased by the difference in this structure of sub-pixels.

Enlargements and the schematic diagrams of pixels with a 2M(VA) system, 3M, and 5M, IPS systems, are shown in Fig. 9. The shape of a pixel of 2M(VA) was rectangular or almost square. This indicates that MTFs of a VA system in the horizontal and vertical directions were almost the same. In the IPS system, the boundary of a pixel in the horizontal direction was mostly straight, but the boundary of a pixel in the vertical direction was zigzag when the shape of the pixel was not rectangular. Therefore, the boundary of a “zigzag” bar faded, and was considered to decrease MTF in the vertical direction.

The LCD display was controlled by a thin-film transistor. In the case of CRTs, it was controlled by the inclination of the electron beam in CRT displays. In CRT displays, dispersion of the light according to spot size and the fluorescent substance of the electronic beam were

Fig. 9 Structure of sub-pixels of LCDs used in this study. Upper layer is an enlargement of pixels. Middle and lower layers are schematic diagrams of pixels. Middle layer shows pattern diagrams when the bar of one pixel is horizontally displayed. Lower layer shows pattern diagrams when the bar of one pixel is vertically displayed.

the factors responsible for lack of sharpness.

There has been much research regarding MTFs in the horizontal direction of a CRT display.⁴⁾ However, research is very limited regarding MTFs in the vertical direction of CRTs and the MTFs of LCDs. This is because these characteristics are discrete. We suggested a method of measuring MTF in the case of a discrete value. It has recently begun to be used to measure the MTFs of LCDs, and it remains to be determined what

kind of influence the values will have on diagnosis.

4. Conclusion

We measured the MTFs of LCDs and a CRT display. The MTFs of LCDs were affected by differences in size, pixel shape, structure, and operation mode of the liquid crystal, as well as by the number of pixels. MTFs of the LCD were higher than those of the CRT display.

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図表の説明

- Fig. 1 バーパターンを用いた医用画像ビューアのMTF測定法の流れ
 Fig. 2 ディスプレイに表示するバーパターン画像
 Fig. 3 液晶ディスプレイの水平方向のMTF
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 中段：1画素幅のバーを水平に表示した場合の模式図
 下段：1画素幅のバーを垂直に表示した場合の模式図

Table 今回の研究で使用したディスプレイの仕様