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PACS Component: Evaluation of Totoku 3 MP Greyscale LCD Flat-Panel Display

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Summary

This report gives a technical evaluation of a Totoku flat-panel display device (see Figure 1). The device is a greyscale display suitable for use in diagnostic medical imaging. It utilises an Active Matrix Liquid Crystal Display (AMLCD) with a three mega-pixel (3 MP) display matrix. The display was evaluated in combination with a Matrox graphics card, recommended by Totoku as being appropriate for use with this type of display and, together with the examples of the displays, loaned by them for the period of the evaluation.

The device was tested for luminance consistency and uniformity, variation of luminance with viewing angle, contrast resolution and spatial resolution and was found to perform well under all tests.

Please note that the quality of the reproduced images within this report does not necessarily reflect the quality of the image as seen on the display device itself.

Figure 1. The Totoku 3MP display

1 An introduction to display device technology

1.1 Liquid Crystal Display (LCD) technology

With the advent of digital imaging systems it has become increasingly common to view medical images on electronic soft-copy display devices rather than film. This has many advantages, not least the cost-saving involved in not printing film and managing its storage. For many years the dominant technology in electronic displays has been the cathode-ray tube (CRT), as it has been in television viewing in the home. Recent years, however, have seen the development of a number of alternative technologies for such small displays, including plasma, liquid crystal and projected displays. This report evaluates a display that uses liquid crystal display technology.

Liquid crystals exist in a state that displays some of the characteristics of a solid (i.e. molecules in the crystal are fixed in orientation within the material) and some of the characteristics of a liquid (i.e. the molecules are free to move around while maintaining that fixed orientation). A substance can exist as a liquid crystal over a relatively narrow temperature range; any higher than this range and it becomes a normal liquid and any lower and it becomes a normal solid. Liquid crystals can exist in several different “phases” displaying different characteristics, and it is a particular instance of one of these phases that is used in liquid crystal displays – the “nematic” phase.

In the nematic state, the liquid crystals are naturally aligned. They can be forced to change their alignment by application of an electrical voltage across the crystal. The degree by which they change alignment can be controlled predictably by the amount of voltage applied. As the alignment changes, the polarisation of any light passing through the crystal is affected in a similarly predictable fashion. It is this property that makes liquid crystals suitable for use in display devices.

Liquid crystals are used in displays by sandwiching them between two layers of glass. On either side of this sandwich are placed two polarising layers. These two layers of polarising material have planes of polarisation that are perpendicular to each other. A backlight is placed on one side of the sandwich and the light from this passes through the first layer of polarising material, causing it to be polarised. The plane of vibration of the light is modified by the liquid crystal according to the alignment of the crystal, which in turn is controlled by the voltage across it. This voltage is applied by electrodes on one side of the liquid crystal cell, hence this particular construction is referred to as ‘In-Plane Switching’. Finally, the transmitted light reaches the front polarising layer, and the amount of light allowed through this layer is dependent on the plane of vibration of the light in relation to this second polarising layer. By adjusting the orientation of the molecules, the plane of vibration of the light can be modified and thus the amount of light passing through can be controlled.

1.2 Advantages and disadvantages of LCD technology

Viewing angle
LCDs have a narrower usable viewing angle than CRTs due to the features of the technology used. Luminance and contrast can vary significantly as viewing angle changes. LCD devices should be viewed from directly in front of the display.

Refresh rate
The technology used to construct flat-panel displays means that there is no ‘flicker’ apparent to the viewer. However, the screen refresh rate is relatively slow compared to CRT displays and so motion artefact can be apparent with moving or fast-changing images.

Luminance
Flat-panel displays are capable of high luminance and can work well in brightly-lit areas. However, they are often not capable of black levels as low as CRT displays and so often suffer from reduced contrast.

Resolution
The resolution of an LCD display is fixed at the time of manufacture. At the native resolution of the panel the resolution is exact. Should it be required to display images at different resolutions, the image data will need to be rescaled before display. This rescaling can introduce distortion in the displayed image.
Displays using CRT technology, however, can easily be switched between different resolutions without noticeable loss in display quality.

Size and shape
Flat-panel displays are, in general, lighter than CRT displays and have a smaller footprint. Their screens are flat, thus providing a more faithful reproduction of the original captured image.

Power consumption
Flat-panel displays consume less electricity and produce less heat than CRT displays.

Focus and sharpness
Where CRTs require careful focussing to produce the sharpest image, LCDs are perfectly sharp – although consideration must be given to any difference in resolution between image data and the display (see *Resolution,* above).

Geometric distortion
In general there is no geometric distortion with flat-panel LCD displays. If images require to be rescaled for display it is possible that this may introduce minor distortion.

Bad pixels and screen uniformity

LCDs can have ‘stuck’ pixels - pixels which are permanently on or off. Some pixels may be improperly connected to adjoining pixels, rows or columns. Also, the panel may not be uniformly illuminated by the backlight resulting in uneven intensity and shading over the screen. The screen glass itself may also contribute to non-uniformity in the displayed image.

2 Evaluation methodology

The evaluation methodology used was based on the AAPM TG18[1] "Assessment of Display Performance for Medical Imaging Systems" document (draft version 9, October 2002, now published in the final version listed in the References section of this report), with local variation as required. The devices were evaluated in a darkroom. Devices were evaluated as a complete system, i.e. the performance of the display was not separated from the performance of the supplied graphics controller card.

2.1 Tests performed

1. Physical description of device

1.1 Size, weight, etc

1.2 Build quality

2. Operating conditions

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3. Technical description

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3.4 Refresh rate

4. Assessment of display performance

4.1 Geometric distortions

4.2 Display reflections

4.3 Luminance response

4.4 Luminance uniformity

4.5 Luminance stability

[1] AAPM TG18: American Association of Physicists in Medicine Task Group 18

4.6 Contrast ratio

4.7 Spatial resolution

4.8 Display noise

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4.10 Electronic cross-talk

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5. Assessment of software performance

5.1 Description of functionality offered

5.2 Testing functionality and ease of use

3 Device description

The supplied devices were tested attached to a standard PC owned by PACSnet.

Make and model: Dell Dimension 8100

Operating System: Windows 2000 Professional v5.00.2195 SP 3

CPU: Pentium 4, 1.5 GHz

RAM: 256 MB

HDD: 74.5 GB

Displays supplied:

Two displays were supplied for use during this evaluation. These were a pair of 3 MP greyscale displays intended for the display of diagnostic-quality images. They each used a clear base for the display (i.e. there was no colour tint to the displayed monochrome images).

Screen 1:   Model: Totoku ME315L

Screen 2:   Model: Totoku ME315L

The displays were supplied with a single dual-head Matrox graphics card. This card was installed in PACSnet's PC together with the appropriate drivers.

Graphics Card: Matrox MED 3mp-DVI-English

3.1 Physical description of device

Figures quoted are those provided in the manufacturer's literature.

3.1.1. Size, weight

Casing dimensions:

The device has the following dimensions when the screen is attached to its stand and is in portrait mode:

Height:	522 - 583 mm
Width:	367 mm
Depth:	220 mm
Weight:	10 kg approx.

3.1.2 Build quality

The displays were of the quality required for use in the expected environments. There were no reasons apparent that would cause any problems in normal use.

Figure 2 shows the rear of the display and its stand. The stand allows for the display to be adjusted for height and tilt and for rotation between portrait and landscape orientation.

Figure 2. The Totoku 3MP display stand and rear of display unit

3.2 Operating conditions

Figures quoted are those provided in the manufacturer's literature.

3.2.1 Temperature and humidity range

Operating conditions:

Temperature: 5 °C to 35 °C

Humidity: 30 % to 80 % Relative Humidity (non-condensing)

Pressure: 701 - 1013 hPa

Storage conditions:

Temperature: -20 °C to 60 °C

Humidity: 10 % to 85% Relative Humidity non-condensing

Pressure: 266 - 1013 hPa

3.2.2 Fluid resistance

The device was not intended for use in areas where it might be exposed to water or other fluids. Its resistance to the ingress of fluids was not tested.

3.2.3 Power supply requirements

Power supply required to transformer:

100 - 240 V AC

50 / 60 Hz

1.0 - 2.0 A

Power supply required to display:

12 V DC

6.6 A

Power consumption:

In normal operation:	80 W approx.
In power save mode:	Less than 10 W

3.3 Technical description

Figures quoted are those provided in the manufacturer's literature.

3.3.1 Screen size – diagonal

530 mm (20.8")

318 mm width x 423.9 mm height (in landscape mode)

3.3.2 Screen size – pixels

Available resolutions:

Portrait: 1536 x 2048, 768 x 1024, 600 x 800, 480 x 640

Landscape: 2048 x 1536, 1024 x 768, 800 x 600, 640 x 480

3.3.3 Pixel size and spacing

Quoted pixel spacing: 0.207 mm x 0.207 mm

3.3.4 Refresh rate

30 Hz for 1536 x 2048 display resolution.

3.3.5 Luminance

700 cd/m^2 maximum.

Note that the display was set to a peak luminance below the maximum, to more accurately reflect typical use.

4 Assessment of display performance

4.1 Geometric distortion

The display was evaluated for geometric distortions by displaying the TG18-QC test image from the AAPM image suite.

In a Liquid Crystal Display, pixel positions are fixed and are determined by the position of the individual cells. Therefore, in a properly designed and manufactured display, there should be no geometric distortion apparent. In the display under evaluation there was, as expected, no discernible distortion in the horizontal or vertical direction.

To establish that there was no geometric distortion, a test pattern of squares (AAPM TG18-QC) was displayed and the size of the squares measured. The results were:

One square:	21 mm x 21 mm
Two squares:	42 mm x 42 mm
Four squares:	84 mm x 84 mm
Full screen horizontal (20 squares):	420mm (i.e. 21 mm/square)
Full screen vertical (12 squares):	252 mm (i.e. 21 mm/square)

It was demonstrated that there was no measurable geometric distortion in the displayed test image. No distortion was seen in inspection of any other test images used during the evaluation.

4.2 Display reflections

No formal measurement of the reflectance of the display screen was performed. Subjectively, the display reflectance was similar to other displays in its class.

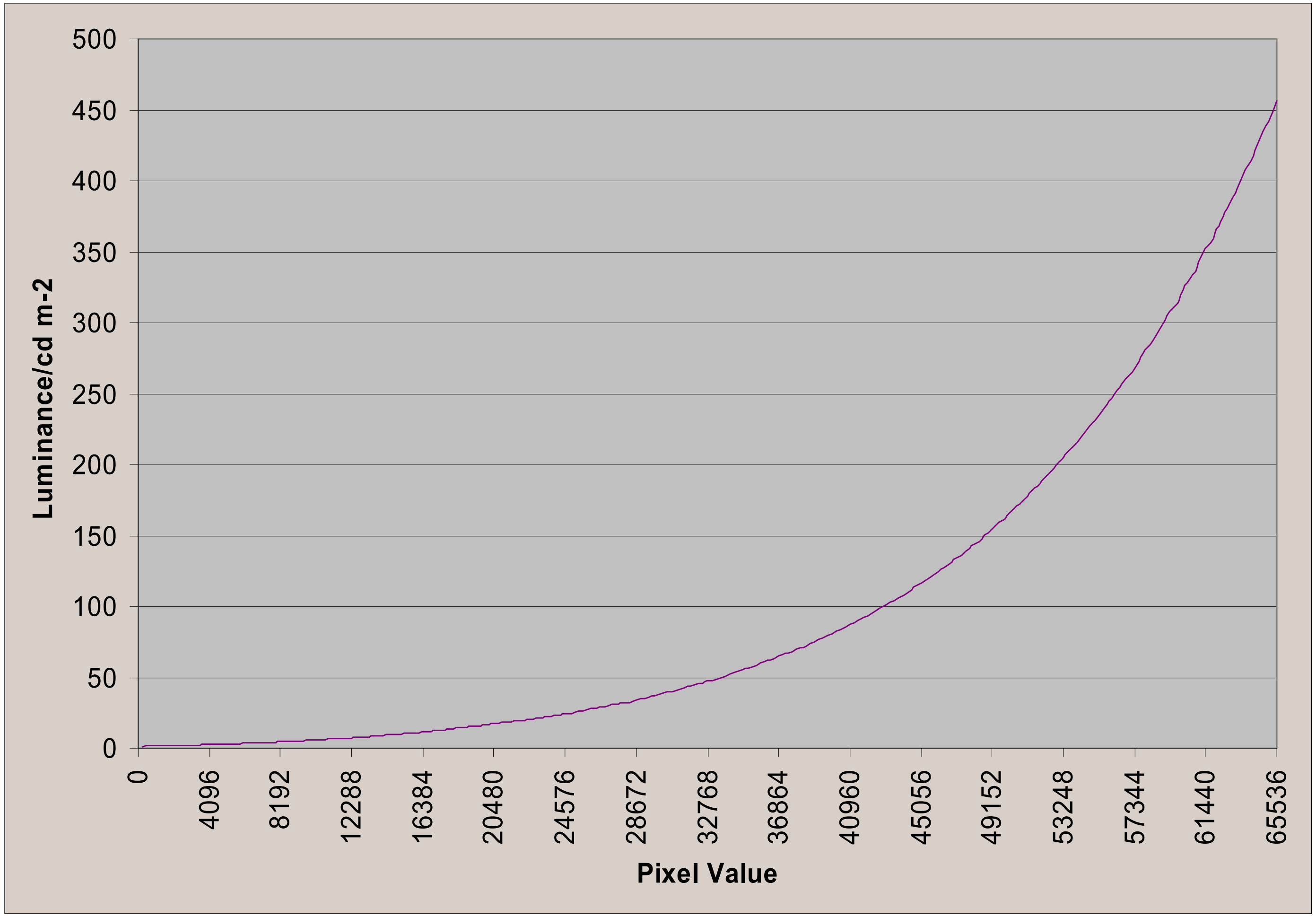
4.3 Luminance response

Figure 3 shows the results of measurements of luminance over the complete range of pixel values, using PACSnet's luminance meter to measure the screen luminance.

For clarity, the graph shows the results from only one set of measurements. All measurements produced similar result.

As can be seen from the curve, there is a smooth and steady increase in measured luminance as the image data pixel value increases. The shape of the curve matches that expected for a standard DICOM Gray Scale Display Function calibration.

Figure 3. Luminance response



4.4 Luminance uniformity

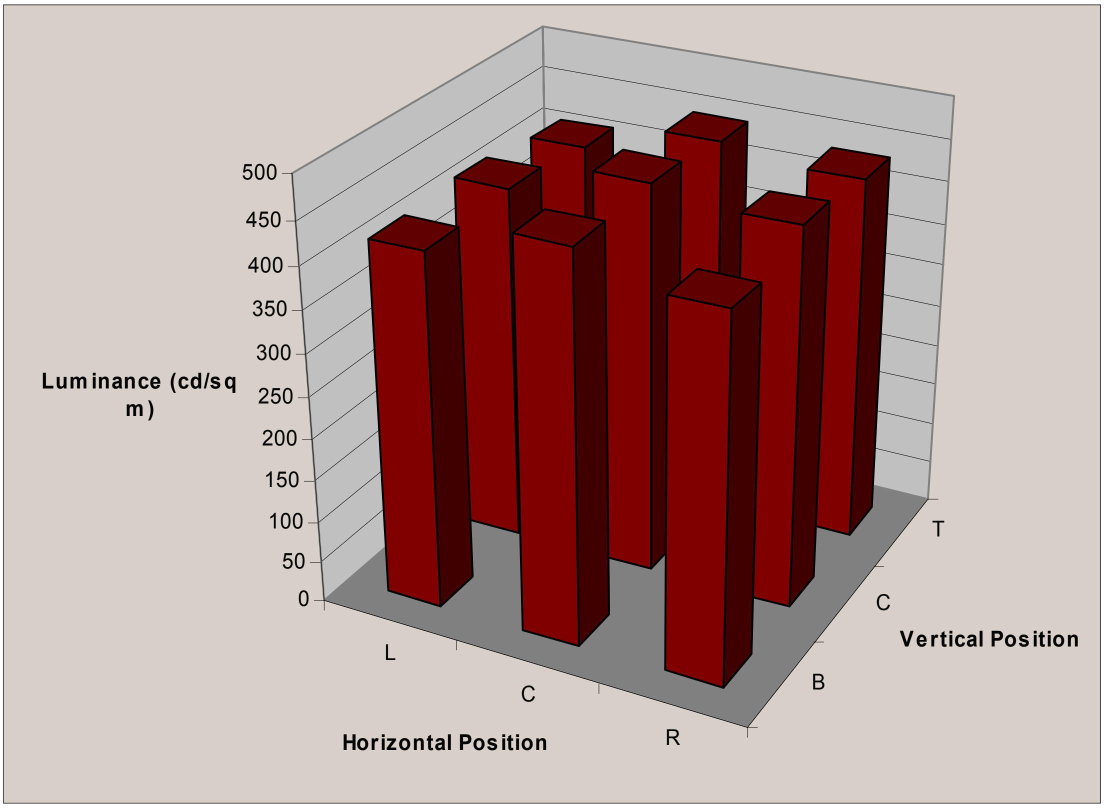
Luminance uniformity was measured by displaying the AAPM TG18 UN and TG18 UNL test images and taking measurements of the luminance at 9 points over the screen for each image using PACSnet's luminance meter.

Using the UNL test image, mean results of the measurements for each point (in cd m^{-2}) were:

437	449.5	411.5
449.5	463	425
430	460.5	421

These results are plotted in Figure 4.

Figure 4. Luminance uniformity



The AAPM TG18 Display Assessment protocol states that the maximum luminance variation should be less than 30%, this luminance variation being calculated by the formula $L_{var} = 200 * (L_{max} – L_{min})/(L_{max} + L_{min})$.

In the above case, the maximum variation is

L_{var} = 200 * (463 – 411.5)/(463 + 411.5) = 11.8%

When measured using the TG18 UNL test image, the luminance variation over the display screen falls below the upper limit recommended by the AAPM and is therefore acceptable.

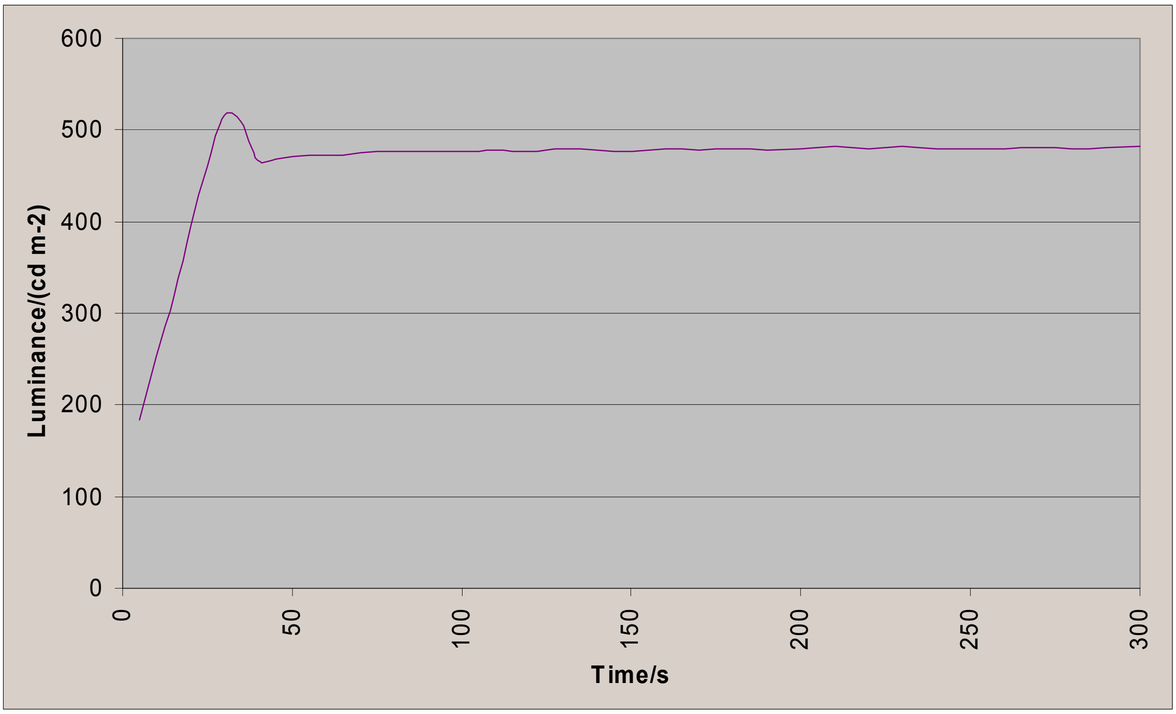
4.5 Luminance stability

The stability of the luminance of the display was measured, both short-term luminance changes following switching on the device and longer-term drift over several hours.

4.5.1 Luminance changes following switching on the device

To measure the luminance changes here (the "warm-up" time), the system was set up to display a white square at peak luminance at the centre of the display. The display was then powered on and luminance readings taken every few seconds until the display luminance had stabilised. Results are shown in Figure 5.

Figure 5. Warm-up time for the Totoku 3 MP display



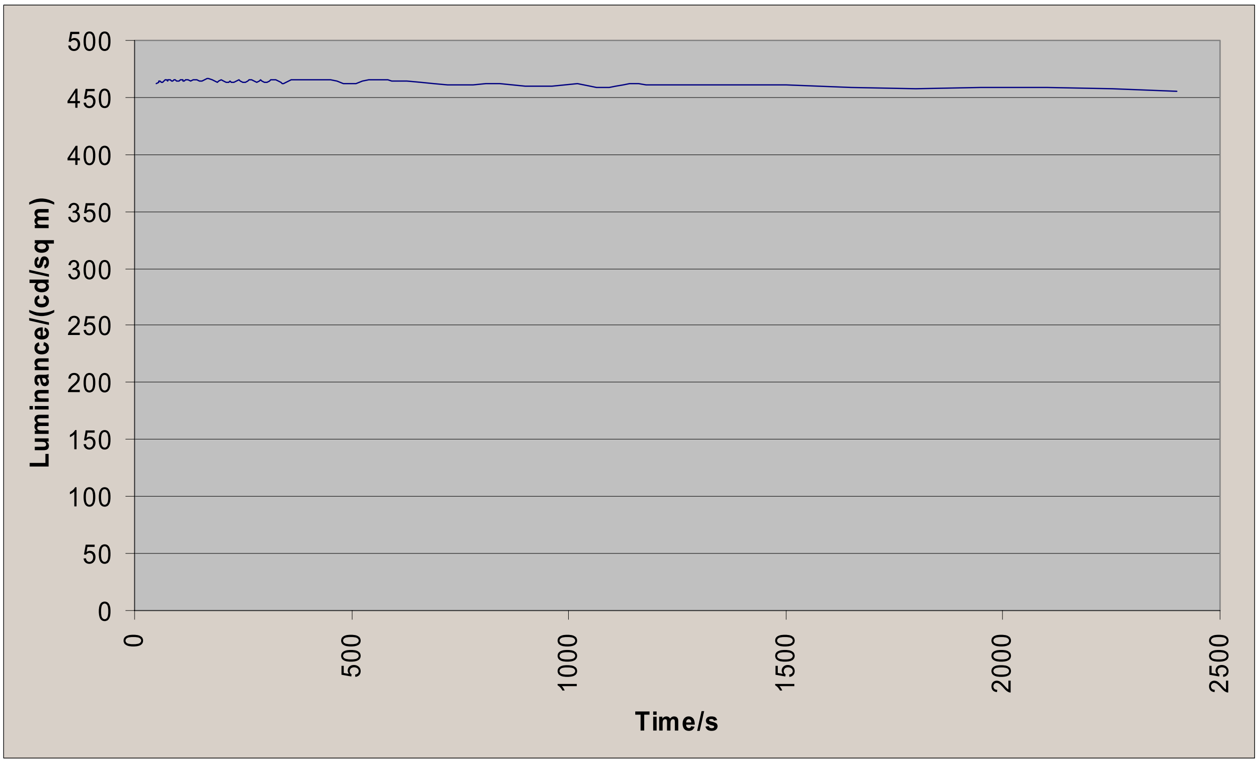
It can be seen that the device reached its target luminance and remained there after approximately one minute. In normal use, this would be well within the time required to start up the base PC and for the user to log in.

Note the small peak after approximately 30 seconds. This occurs once the backlights have warmed up sufficiently to allow them to provide more than the required minimum luminance when driven at the maximum current. Once this occurs, feedback from the internal luminance probe allows the backlight current to be reduced so that the desired operating luminance of the backlights is maintained.

4.5.2 Long-term luminance drift

To measure any long-term drift in luminance, the display was switched on and displayed a test image in the same manner as for the warm-up measurements above. Measurements were taken for a significantly longer period and the results are shown in Figure 6.

Figure 6. Luminance stability



It can be seen that over the measurement period there was no significant drift in the peak luminance value measured.

4.6 Contrast ratio

The contrast ratio was measured using the method described by the American National Standards Institute (ANSI). This requires the display of a 4 x 4 “checkerboard” pattern, with eight areas at peak white and eight areas at black. The luminance of each of these areas is measured and the luminance ratio is calculated by dividing the mean luminance of the white areas by the mean luminance of the black areas. The display is masked, apart from an aperture for the area being measured, during this test. The tests were performed with the display screen in portrait orientation.

Results:

Mean white luminance: 436.3 cd/sq m

Mean black luminance: 0.57 cd/sq m

Calculated contrast ratio: 765:1

The calculated value of 765:1 for the contrast ratio comfortably exceeds the minimum value of 400:1 recommended by the AAPM and is therefore acceptable. The calculated value also exceeds the “600:1 (typical)” value quoted in the Totoku specification sheet.

4.7 Spatial resolution

The display resolution was evaluated using the AAPM TG18 test image. As expected, the limiting factor for the resolution was the size of the pixels. With test images displayed at 1:1 image pixel:display pixel (i.e. at 1536 x 2048 pixels image size) there was no loss of spatial resolution.

4.8 Display noise

No objective measurement of display noise was possible since this requires use of specialist imaging equipment which is not within the PACSnet collection.

Subjectively, however, noise levels appeared very low and did not interfere with use of the displays.

4.9 Angular dependency of luminance

The apparent brightness of displays can vary considerably with viewing angle. This is especially true for LCD flat-panel displays. This variation of luminance can affect not only the perceived brightness of the displayed image, but also its contrast. The same image viewed from different angles can convey quite different information. This can often be undesirable – for example, two people sat side-by-side looking at the same screen will expect to see the same image – but can sometimes be desirable, for example when personal information is displayed on screens in public areas. In this second case, if the useful viewing angle is very narrow then viewing the information on the screen can be restricted to a person positioned directly in front of the screen only.

Figure 7 shows the variation of peak luminance as viewing angle varies horizontally, with the display in portrait mode.

Figure 7. Variation of luminance with viewing angle - horizontal

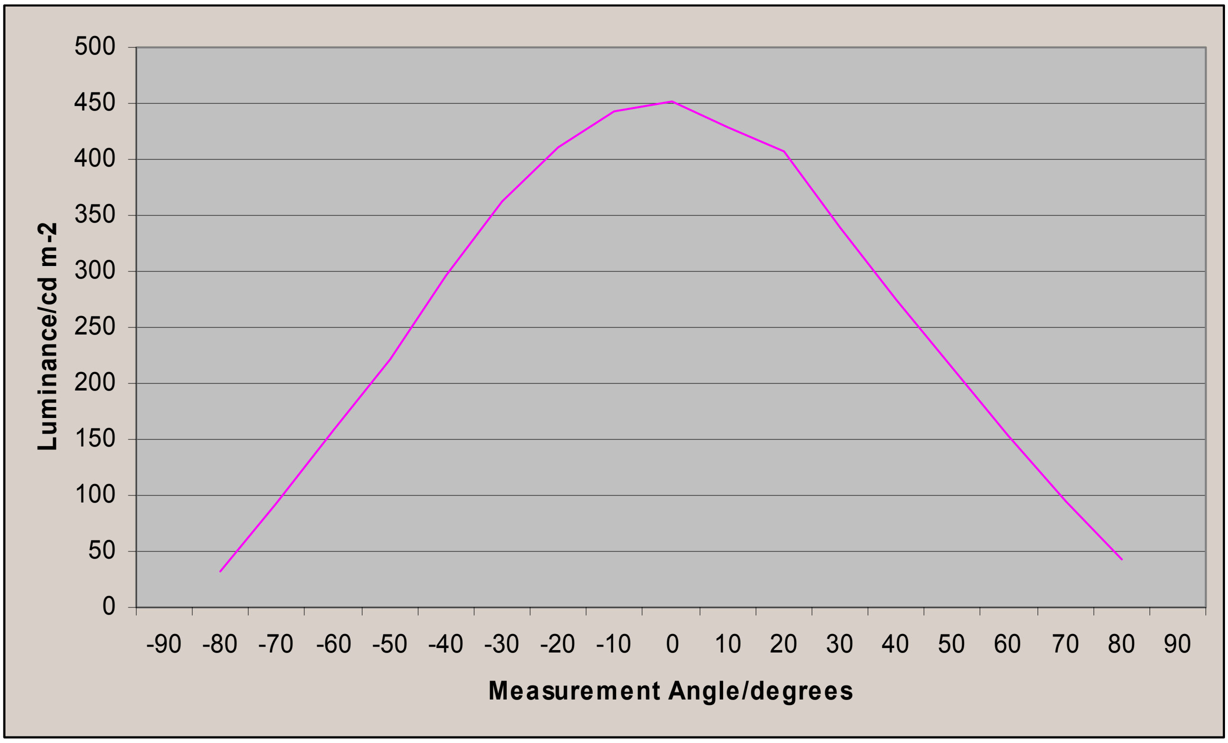
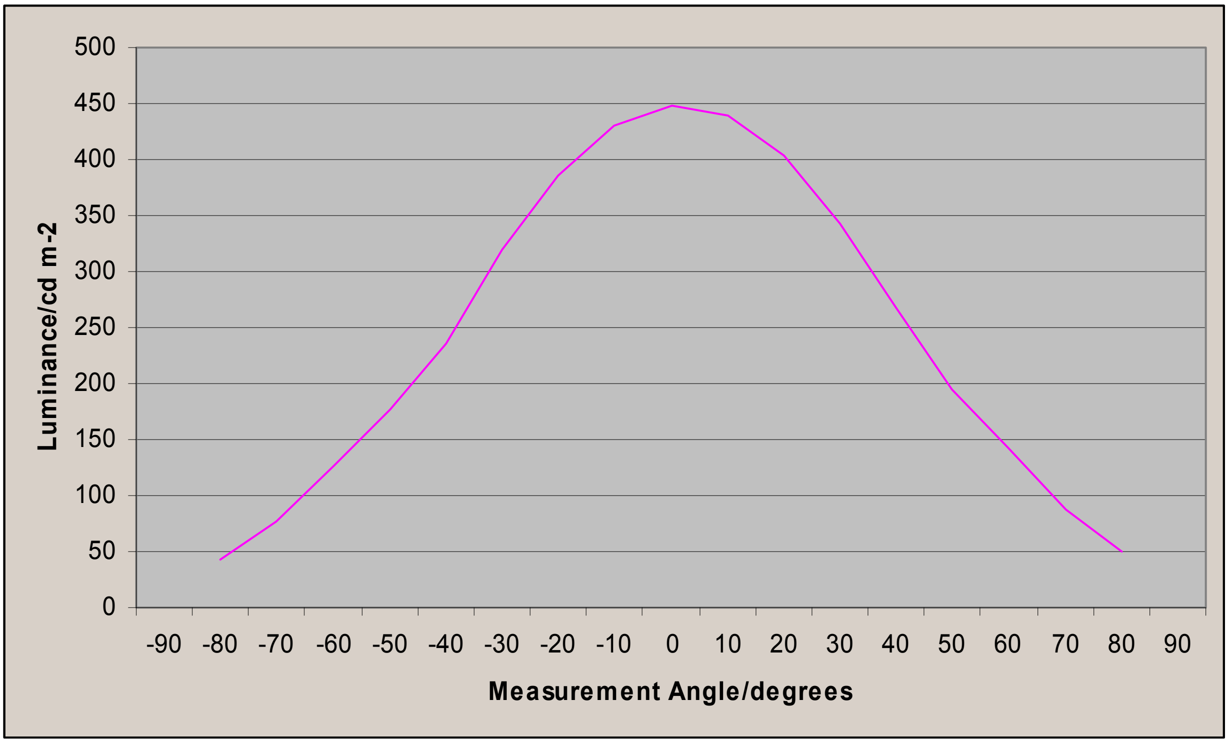


Figure 8 shows the variation of peak luminance as viewing angle varies vertically, with the display in portrait mode.

Figure 8. Variation of luminance with viewing angle - vertical



4.10 Electronic cross-talk

Cross-talk is the unwanted leakage of electronic signal from one channel to another, usually adjacent, channel. In liquid crystal display systems this can lead to the intended luminance of a pixel (i.e. the intended voltage across the liquid crystal cell that forms the pixel) being modified away from the intended value.

There was no effect from cross-talk apparent on a visual inspection of the displayed image.

4.11 Pixel defects

There were no pixel defects apparent to a visual inspection of the display.

5 Assessment of software performance

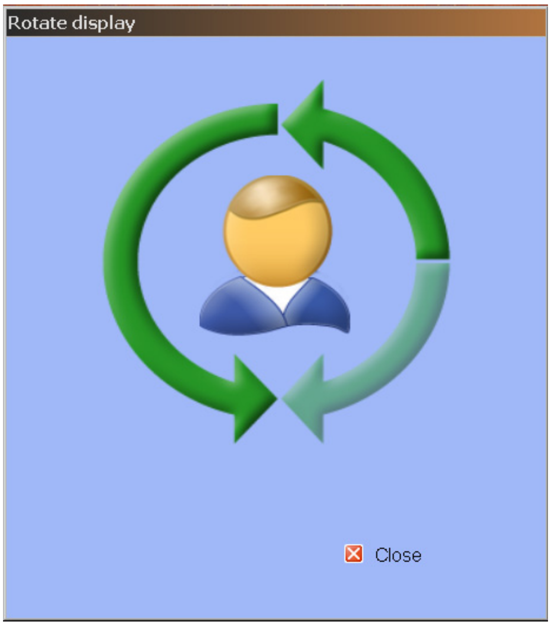
5.1 Description of functionality offered

Additional software provided with the graphics card included Matrox's PowerDesk display set-up software.

5.1.1 Display software

The software provides features additional to the standard Windows display control, including the ability to adjust screen orientation; the choice of use of one or multiple displays; the choice of display mode (stretched or independent, i.e. whether an image can spread over multiple screens or fill one screen at most).

Figure 9. Matrox PowerDesk on-screen image rotate facility



6 Conclusions

The Totoku ME315L 3 MP LCD Flat-panel display is, in the authors' opinion, a well-manufactured product, with features that make it suitable for use in diagnostic medical imaging, including high contrast ratio, little luminance variation across the screen and good luminance stability over time. As is expected of displays using LCD technology, there is no geometrical distortion in the displayed image.

The display also offers good conformance to the DICOM Part 14 Grayscale Display Function.

7 Acknowledgements

The display under evaluation was supplied by:

TaraMed Distribution Ltd,
Ballymoss Road,
Sandyford Industrial Estate,
Sandyford,
Dublin 18.
Ireland

8 References

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Data Projection Equipment and Large Screen Data Displays -- Test Methods and Performance Characteristics, American National Standards Institute (ANSI) IT7.215-1992, 1992.

9 Bibliography

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Appendix 1: Luminance meter

The luminance meter used in this evaluation was a Hagner S3 Universal Photometer/Radiometer. This is a combined luminance and illuminance meter.

The light sensitive components of the meter are two silicon diodes, each filtered to give a spectral response close to that of the human eye (i.e. the spectral response correlates with the CIE 'standard observer' curve). One of the diodes is internal and is used for the measurement of luminance within a 1º circular field. The second, external, diode is used for the measurement of illuminance and was not used in this evaluation.

The meter is portable. It can be powered by either an internal 9V battery or an external 9-12 V DC power supply. The measurement range of the meter for luminance is 0.01 – 200,000 cd m^{-2}, with a quoted accuracy of ±3 % (±1 in the last digit). Its focussing range is 0.5 m - ∞. Polarised light (such as that typically emitted from an LCD flat-panel display) is measured correctly.

The dimensions of the meter are 270 mm x 130 mm x 70 mm. Its weight is 1.4 kg (or 2.0 kg in its carrying case).

Appendix 2: Manufacturer's comments

No comments regarding the contents of this report were received from the manufacturer or the distributor of this display.